HISTORY

OAR-4

PROJECT CATEYE

A HISTORY OF LIGHT AMPLIFICATION RESEARCH at the AERONAUTICAL RESEARCH LABORATORY 1952–1960

OFFICE OF AEROSPACE RESEARCH U S AIR FORCE

PROJECT CAT EYE:

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March 1962

Historical Division
Office of Information
Office of Aerospace Research
Washington, D. C.

FOREWORD

Basic research, as the purists constantly remind us, is a pursuit of scientific knowledge *per se* whose essential function is to maintain the flow of new data and ideas on which all progress in either military or industrial technology must be based. Applied research, by contrast, seeks to use or expand scientific knowledge for the sake of specific practical objectives. Project Cat Eye fulfilled both of these roles during its period of activity at the Aeronautical Research Laboratory of the Office of Aerospace Research (OAR). It was, in fact, a notably fruitful research effort in the electronics area, which demonstrated the feasibility of amplifying light levels by over *twenty billion* times; and though its objectives never included the development of operational equipment, it investigated new techniques which could be used as a basis for such development. This project is now the subject of the present historical monograph, which was undertaken by Mr. Garé P. LeCompte while he was assigned to the OAR Historical Division. Although Mr. LeCompte was not on hand to take part in the final round of revisions and editing for publication, it is also true that the study never would have come into being without his initial enthusiasm.

At the outset, neither Mr. LeCompte nor anyone else in the Historical Division expected that the Cat Eye history would grow to its present dimensions. Yet there is probably good reason -- over and above the immediate importance of the Cat Eye project -- for devoting so much attention to this topic. Since it is manifestly impossible to give historical coverage to the entire field of Air Force research, the historical program must concentrate on particular projects or research areas that are broadly illustrative of Air Force research problems and procedures, more or less comprehensible to the layman, and/or especially noteworthy for their accomplishments. Project Cat Eye, meeting all these requirements to a significant degree, makes an unusually good theme for a case study in Air Force research operations.

This history is devoted primarily to the Cat Eye research effort itself. Therefore, except for the discussion of a few special test programs, the current and potential uses of the principles and techniques that were investigated are at most suggested briefly or considered in general terms. As mentioned above, Cat Eye was not a development project -- even though the project staff was fully aware of the possible operational applications and seldom lost an opportunity to encourage their development by organizations whose mission clearly lay in the technical development field. Also, the history deals at considerably greater length with the human and organizational aspects of the research effort than with the purely scientific and technical details, which have been meticulously recorded in a series of published technical reports. The technical aspects are touched on as briefly and simply as possible in the text itself but receive some additional treatment in two special appendixes. One of these is a general discussion mostly written by (or adapted from the technical reports of) the project scientist, Mr. Radames K. H. Gebel; the other is a bibliography of relevant technical reports, listed with their abstracts.

Although the point is discussed again in a rather lengthy note at the bottom of page 9, this Foreword should make mention of the way in which the term Cat Eye will be used throughout the study. All too often the term has been used indiscriminately as referring to a research project in the field of light amplification, a particular system of amplification, or some apparatus incorporating the principles of that system. In this study, however, only the first usage will be followed, as the others lead to confusion of various sorts both between the Cat Eye effort and other work in the same field and between different stages of the Cat Eye project itself. Perfect consistency may not have been attained on every page, but at least the reader is urged to bear in mind the usage that is intended.

David Bushnell
Historical Division
Office of Aerospace Research
March 1962

ACKNOWLEDGEMENTS

This historical survey was undertaken as a case study in Air Force research activities as conducted at the Aeronautical Research Laboratory, Wright-Patterson Air Force Base, Ohio. While it primarily concerns the work of Project 7072, Research on the Quantum Nature of Light, at one Air Force laboratory, the study may also be construed as throwing some light on the problems and achievements of Air Force research in general. Dr. Knox Millsaps, Chief Scientist of the Office of Aerospace Research, originally suggested the Cat Eye project as a topic for historical treatment and helped to provide depth of perspective concerning the early periods of the research.

Many people, too numerous to mention in each case by name, have graciously donated their time for interviews and for reviewing of the study in draft form. At Headquarters Office of Aerospace Research these included Colonel Robert G. Ellis, Director of Plans; Lieutenant Colonel William G. Ashley, Chief of the Analysis Division in the Plans Directorate; and Lieutenant Colonel Charles J. Lyness, Chief of the Electronics Division in the Directorate of Research Programs. All were most helpful in clarification and review of both technical and administrative details.

At the Aeronautical Research Laboratory I was aided by Edwin J. Callan, Executive Secretary to the Research Council; Everett G. Whitacre, Information Officer; Roy R. Hayslett, assistant to R. K. H. Gebel; and, above all, Dr. Lee Devol, Chief of the Solid State Physics Research Branch, and R. K. H. Gebel, the creator of the Cat Eye project. Without the unselfish assistance of Dr. Devol and Mr. Gebel, and their encouragement to analyze the maze of material, this survey would not have been possible.

Special mention must also be made of Major General Albert Boyd, USAF (Retired), formerly Commander of the Wright Air Development Center (WADC) and currently Vice President of the Defense Products Group

of the Westinghouse Electric Corporation; and Dr. J. Allen Hynek, formerly Associate Director of the Smithsonian Astrophysical Observatory and currently Director of the Dearborn Observatory of Northwestern University. In spite of their heavy schedules, General Boyd willingly undertook to review the description of the early stages of Cat Eye research at WADC, and Dr. Hynek provided a critical review of the cooperation between the Cat Eye project and the Smithsonian Institution in connection with the International Geophysical Year. Similarly, Dr. John E. Clemens, formerly head of the Physics Research Branch of ARL and now with the United Shoe Machinery Company, gave freely of his time in discussing the project origins, and Chief Master Sergeant E. T. Tyson, Jr., of the Aeronautical Systems Division, was extremely helpful in providing data with regard to the test program undertaken in collaboration with the Smithsonian Astrophysical Observatory.

I have worked on this study while assigned to two different historical offices. The study was initiated and largely written at the Historical Division, Office of Aerospace Research, where Dr. David Bushnell, Chief, and Mr. Samuel Milner, Deputy Chief, served as guides, reviewers, and severe critics of this survey. However, Mr. Harry C. Jordan, Division Historian of the Electronic Systems Division, rendered invaluable service by allowing me to complete my manuscript after transfer to his Division and also by offering professional advice as needed. To these Air Force historians, as well as to all the other individuals who have helped me in the course of preparing this history, I would like to express my sincere appreciation.

Garè P. LeCompte
Electronic Systems Division
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November 1961

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Chapter I

ORIGINS OF CAT EYE

The Aeronautical Research Laboratory (ARL), at Wright-Patterson Air Force Base, Ohio, "conducts and sponsors basic research in the areas of interest to the Air Force in the physical and aerodynamic sciences."[1] By virtue of its basic research mission, it is assigned to the Office of Aerospace Research rather than to the Aeronautical Systems Division, which is located at Wright-Patterson but is primarily engaged in applied research and systems development. The caliber of ARL's research staff and the significance of its contributions to knowledge have won wide recognition within the nation's scientific community, but ARL is much less well known to the general public. This is only to be expected, since basic research by its nature produces fewer headlines than the development of new military systems. Nevertheless, there are some ARL contributions which have combined high intrinsic importance with an unusual degree of general interest. One of these is the work performed at ARL in the field of light amplification, under the principal direction of Mr. Radames Kurt Horst Gebel.

The origins of this accomplishment go back to the period of Operation Paperclip, which brought many talented German and Austrian scientists to United States research establishments immediately after World War II. Among them was Gebel, who had been with Zeiss-Ikon during the war and then served as consulting electronic engineer with the British naval research program for a little over a year. Gebel was brought as a Paperclip scientist to the Office of Air Research (from which ARL developed*) at Wright-Patterson Air Force Base, primarily because of

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* The Office of Air Research is not to be confused with the present Office of Aerospace Research, although the two obviously have features in common. The Office of Air Research was established at

his wartime research and development work on military control systems, such as Zue, Zuema, and Hirsh. These are guidance devices which were operationally used in tanks, submarines, and night fighters.

Gebel arrived at ARL in 1948, in the midst of a challenging period for Air Force research and development. The breakthrough into jet and supersonic propulsion had brought with it many scientific and technical problems which were radically new or at least had not been encountered previously on a significant scale. Initially, he found himself in the same position as many other German scientists -- unfamiliar with the English language and lacking adequate research equipment. However, after the Paperclip scientists discovered a large collection of electronic parts left over from the war period, known as the "Cambridge stocks," Gebel and others were able to improvise what they needed to begin research.[2] Gebel himself undertook research in his own specialization of electronic systems and optical test equipment.

In due course, Gebel was called upon to collaborate in a program of research in the area of electro-optical systems that was the outgrowth of an Air Force contract initiated in 1948 with the Freed Radio Corporation. The objective of this contract, which was monitored by

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Wright-Patterson Air Force Base in February 1948 as an agency of the Air Materiel Command. When the Air Research and Development Command (ARDC) was established in 1951, certain functions of the Office of Air Research -- notably in the monitoring of research contracts -- were transferred to the headquarters staff of the new command organization. What remained at Wright Field of the Office of Air Research was then renamed Flight Research Laboratory and became part of ARDC's Wright Air Development Center. In May 1953, the Flight Research Laboratory was renamed Aeronautical Research Laboratory (ARL). The Wright Air Development Center has since evolved into the present Aeronautical Systems Division of Air Force Systems Command. ARL, however, was separated from the rest of the Wright-Patterson research and development complex in the first half of 1960, when it became part of the Air Force Research Division, the immediate predecessor of the Office of Aerospace Research.

Mr. Ben B. Johnstone as task scientist, was to obtain a system in which a persistent image from a dark-trace screen could be projected and used like a slide projector in connection with a high-powered light source for tracing the path of an aircraft across the surface of a map.[3] After an Air Force investment of nearly $200,000, the contractor had not succeeded in attaining this goal by use of the methods originally planned. The objective of the research effort was then modified, about 1950, to become the production of a preliminary model of a high-resolution, closed-circuit television system.[4]

This contract modification was in line with the research interests of Dr. John E. Clemens, who headed the Special Projects Section and the Physics Research Group of the Office of Air Research -- two units that were combined in the Physics Research Branch of the Aeronautical Research Laboratory (ARL)* after the Office of Air Research was discontinued and its former nucleus emerged as ARL. Although his own interests were slanted more in the direction of applied than of basic research, Clemens made a large contribution toward providing ARL both with needed resources and with a significant project workload. Moreover, one problem that especially attracted Clemens' attention was that involving the stability of aircraft windows at supersonic speed under the impact of high skin temperature and high aerodynamic pressure. One possible answer to this problem was the concept of a "flying coffin," an aircraft without windows; and Clemens in fact became committed to the idea of eliminating aircraft windows, placing the pilot in a prone position,** and then affording him a clear field of vision by means of

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* At the time the two units were combined, ARL was known as the Flight Research Laboratory, but to introduce this designation in the text would cause undue confusion. It is much simpler to use the term ARL from here on -- whether referring to the present ARL, to the Flight Research Laboratory, or to those portions of the Office of Air Research that ultimately formed part of ARL.

** The prone flying technique was also under serious consideration at this period as a means of increasing pilot tolerance to acceleration forces.

a closed-circuit and high-resolution television system. It was hoped that such a system would result from the modified contract with the Freed Corporation, which was still monitored by Mr. Johnstone (then serving as assistant to Dr. Clemens at ARL). Although the ultimate goal was a 5000-line resolution, the immediate objective was only 2000-3000 lines. Freed produced a 1000-line system, by using a British pick-up tube of commercial sensitivity, and carried on further research under the contract until its termination in May 1954; but the high resolution was not achieved.

Gebel was assigned to this same effort as an in-house investigator, even though he was frankly skeptical about realizing the objective of a 5000-line (or even 3000-line) television system. Such systems were theoretically possible, but they called for accomplishments which were beyond the state of the art as it existed at that time. Hence Gebel suggested that, instead of endeavoring to reach higher stages of resolution, research should be carried out in the area of low light levels, aiming at modest resolution but high sensitivity. Even with a readily obtainable resolution, he felt, a system with sensitivity to excel the unaided human eye would be extremely valuable for future military applications.

As Gebel anticipated, work on the high-resolution, closed-circuit television system proved extremely complex from an engineering standpoint. However, Gebel himself, on his own initiative, began to investigate the feasibility of excelling the sensitivity of the unaided human eye by means of a special apparatus that would amplify extremely low levels of light. This was initially an unofficial investigation, which Gebel began about March 1952 over and above his other research duties. Nevertheless, he pushed ahead with it despite both a perennial shortage of funds and the pessimism of those scientists who accepted the popular contention that it was impossible to surpass the sensitivity of the human eye.

The difficulty of obtaining equipment on a restricted budget was at first a serious hindrance to research in the low-light-level area.

Luckily, Gebel's assistant at the time, Mr. Lake Croft, found several old television cameras stored at Wright-Patterson Air Force Base, which were dismantled to find components for possible use in a light-amplification system. By taking advantage of older equipment not in current use, the research effort was able to proceed without draining limited project funds for the purchase of new equipment.

Gebel felt that in order to achieve the optimum in light amplification a scientist should first study and evaluate pertinent data on the human visual organs, and if necessary carry out further fundamental research in this field. As a result, he wrote a study on vision containing new ideas about color perception: "Physiology and Psychological Behavior of Human Visual Organs."[5]

Another prerequisite for a serious study of light amplification was to work out some method of measuring the low light levels which Gebel hoped to detect and amplify. Since no adequate instrumentation for this purpose existed, Gebel had to construct his own low-level light meter. The resulting portable four-unit instrument permits measurement of extremely low luminescence levels with 10^{-8} foot-lambert threshold. The light meter consists of a six-volt source, which is stepped up to 6000 volts by a transistorized nonmechanical chopper and power supply unit; a pick-up unit consisting of a photomultiplier transducer with an image converter tube and a Leitz 50-millimeter f/1.5 lens; and the fourth unit, the amplifier, which is used for adjusting and calibrating the instrument in addition to amplifying and measuring.[6]

While Gebel continued working on his low-light-level system -- at some sacrifice to the research on high-resolution systems -- Dr. Clemens still emphasized the high-resolution television system to which he was committed. Clemens was sure that the latter system would make an important contribution toward solving the problems of supersonic flight, and he, on his part, was somewhat skeptical about Gebel's low-light-level research. Nevertheless, he permitted Gebel's investigation to continue without hindering it to any great extent.

Simply expressed, Gebel's approach to the light-amplification problem was to focus the image of a low-light-level scene onto a transducer

which converts the optical image into an electrical signal, which is then amplified and modified. A cathode-ray-tube electron beam is then modulated by the signal, and a very bright image of the scene is reproduced on the phosphor screen.* Although the term was not actually used until much later, Gebel's concept can best be described as a sequential light-amplifier system. This designation implies the most important single aspect of the system, which is the fact that it forms from the image information a time-sequential video signal that may be modified and amplified. It is mostly this aspect which made the system distinctly superior to earlier methods of light amplification employing image-converter techniques without the sequence of transducing and scanning.

Gebel had the first real opportunity to demonstrate the feasibility of his approach in the latter part of 1953, roughly a year and a half after the start of his research in this area, when he showed an experimental arrangement in the laboratory to Major General Albert Boyd. General Boyd at that time was Commander of the Wright Air Development Center, which included ARL; and he at once showed great interest in the test set-up, which featured a sealed box containing very dimly illuminated numbers. When the interior of the box was viewed by the unaided human eye through one of two openings, it appeared dark to the observer. After the necessary time lapse to accustom the eye to darkness, General Boyd still could not distinguish the numbers on the opposite side of the box. Gebel then demonstrated the use of low-light-level image amplification by adjusting the optical system of the pick-up unit of his apparatus to the second opening in the box, with the result that the numbers could be seen on the phosphor screen of the reproducer unit with the brightness of daylight. General Boyd was visibly impressed by the demonstration and proceeded to investigate the project more thoroughly. He did not fail to grasp the potential scientific and military uses

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* A more complete technical description of the amplification system as worked out by Gebel is found in Appendix A, "Technical Aspects and Mechanism of Performance." For the basic concept of the system, a patent (#2955158, "Light Amplifier") was issued to the United States Government with Gebel as the inventor.

of light amplification. Moreover, General Boyd is widely credited with inventing the name Cat Eye by which Gebel's project came to be known, although he modestly disclaims that this term originated with him.

General Boyd not only saw to it that a breadboard arrangement was flight-tested at the earliest opportunity but even took part in the first airborne experiment himself. On 15 December 1953 an apparatus consisting of a pick-up portion, associated electronic circuitry, and presentation display unit was installed in a C-47 aircraft at Wright-Patterson Air Force Base. It was then taken aloft for about six hours, in a test that covered light intensities from full daylight to two hours after sunset with cloud cover. The apparatus worked fairly satisfactorily during the entire flight, successfully demonstrating its low-light-level capabilities. At one point General Boyd, who had noticed the poor visibility of the runway while sitting in the cockpit, came aft to witness the image reproduction on the display unit and was greatly impressed once again on seeing the runways reproduced with the brightness of daylight. Another observer, who went along on the same flight, remarked that he would not have believed the results if he had not seen the demonstration himself. What is more, Gebel's calculations indicated that the practical useable limit of low-light-level amplification could be approximately 10,000 times greater than that demonstrated by the breadboard model used in the flight test.[7]

With the initial success of Gebel's light-amplification research proving even greater than anticipated, General Boyd urged immediate technical development of the sequential light-amplifier system. Yet Gebel himself realized that his light-amplification work was still in its early stages and that additional refinements were not only possible but mandatory. He therefore objected that an early program of technical development would be premature and explained the future accomplishments which could be expected to result from further research efforts. The argument Gebel presented was indeed a convincing one, and it was therefore decided to carry out further basic studies before transferring the project to applied research and eventual development for operational use. Dr. Clemens, who had previously favored high-resolution

research as against low-light-level studies, abandoned his insistence upon a high-resolution television system in order to support this work with the resources at his disposal. In effect, Gebel was now encouraged to devote all his energies to research on low-light-level image intensification.[8]

Chapter II

PROJECT ADMINISTRATION AND RESEARCH 1953-1957

By the close of 1953, thanks to the successful flight testing that was carried out in the month of December, Cat Eye* was already ranked as one of the "five most important research tasks" of the Aeronautical Research Laboratory (ARL).[1] Nevertheless, while the testing had demonstrated an amplification gain of 10^5, this was substantially less than the project scientist, Mr. R. K. H. Gebel, believed to be the theoretical potential of low-light-level image-intensifier systems. The testing had also revealed many areas in which much fundamental work was mandatory if the Air Force was to obtain a militarily useable device.

The experimental light amplifier tested in December 1953 made use of commercially available parts, which placed a definite limit on the

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* It must be emphasized that the term Cat Eye, correctly used, stands for a research effort or project, whose objective was to investigate the feasibility of reaching the sensitivity limit imposed on light amplification by quantum mechanics. This is the sense in which the term should always be interpreted in the present history. To be sure, in the beginning the term Cat Eye was also applied to the early amplifier equipment with which R.K.H. Gebel was working at Wright-Patterson Air Force Base, and at that time such usage was clear enough. By and large, however, the term is too easily subject to misinterpretation if used to designate either a piece of hardware or one specific technique of image intensification. The central feature of the Cat Eye research effort was R.K.H. Gebel's conception of a light-amplification system using scanning techniques similar to those used in television, so that his basic idea has also been defined on various occasions as a "closed-circuit television light-amplifier system." But this term is also misleading: for one thing, it is too restrictive. A more suitable designation for Gebel's conception is "sequential light-amplifier system," as already used in the preceding chapter. The fundamental principle of such a system can be applied and exploited in many different ways and with many different components; and though it was carefully explored by the Cat Eye project, the latter never sought to develop a final operational system, which would have been outside the scope of the Aeronautical Research Laboratory's basic research mission.

threshold of sensitivity that could be reached as well as presenting other serious difficulties. The long-range goal, in any event, was to approach the absolute threshold imposed by quantum mechanics while at the same time establishing the feasibility of a transducer for sequential light-amplifier systems that would be suitable for military missions. Gebel had earlier suggested that this might be accomplished by means of a super-image orthicon using intensifier sections before the image orthicon and employing a special target plate; and now that the Cat Eye project had become one of the major concerns of ARL, he proceeded to initiate a series of research contracts designed to obtain such a transducer. The contracts were awarded by ARL to two main contractors: the RCA Laboratories in Princeton, New Jersey, and the Westinghouse Electric Corporation.[2] Under these ARL contracts, RCA worked principally to increase the transducer sensitivity; and Dr. George A. Morton, the RCA scientist most closely associated with the Cat Eye project, has been credited with achieving a genuine "breakthrough in over-all sensitivity of imaging systems."[3] Ultimately Morton, Dr. John E. Ruedy, and associates devised a transducer that made possible (in a sequential light-amplifier system) a useful image intensification of more than 20 billion times -- from a scene brightness of 5×10^{-9} foot-lambert. (Bright moonlight is equivalent to 25×10^{-3} foot-lambert.) At Westinghouse, meanwhile, Joseph Lempert, James Hall, and associates were devoting much of their effort to the problem of microphonics. In due course they succeeded in producing a transducer which had almost no microphonics even under severe vibration and could in fact be considered an item of ruggedized equipment, built to withstand heavy punishment.[4]

The RCA and Westinghouse contractual efforts did not yield sensational advances overnight, for progress was inevitably gradual in a pioneering endeavor such as this. Thus an amplification gain of more than one billion times was not actually demonstrated until 1957, and then only under very carefully controlled conditions. Moreover, simply because the Cat Eye project was in no sense a development effort, the transducers made by the two contractor firms were always

strictly experimental in nature. Dr. Morton, for example, was most careful to make clear that he could not guarantee the duration of useful life of his transducers; they were designed only to demonstrate the attainability of certain research objectives, not to serve as operational prototypes.[5]

In addition to monitoring both RCA and Westinghouse contracts, Gebel continued to conduct an in-house effort at ARL, in which he sought to conceive and investigate new ideas for a more advanced sequential light-amplifier system. Indeed, some of the most interesting aspects of the project were handled primarily on an in-house basis. One example was the investigation of a color capability, which would be of special importance in camouflage detection; on the basis of this work a patent (number 3005108, "Solid State Light Amplifier for Color") was granted to the United States Government with Gebel listed as the inventor.[6] Gebel's in-house work also included the conception and investigation, starting about 1956, of a "background compensation" transducer which permitted the detection and display of moving objects only. The United States Government likewise obtained a separate patent for this device (number 2969477, "Moving Target Indicator with Background Compensation for Visual Light and Near Infrared"), with Gebel as inventor.[7] *

For a more complete technical discussion of all these and other project accomplishments, the interested reader must consult Appendix A at the end of this history and the various technical notes and reports published in connection with the Cat Eye research effort. The present text will be principally concerned with administration and coordination of Cat Eye research and with certain observational and test programs that featured the use of experimental sequential light-amplifier systems. These other activities may not equal the basic scientific and

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* Dr. Morton at RCA also devised a transducer for display of moving objects only, in connection with his contractual work for the Cat Eye project. His approach and Gebel's will be discussed in more detail in Appendix A, "Technical Aspects and Mechanism of Performance."

technical work in ultimate significance, but they consumed a far from negligible amount of time and effort.

Thus one immediate effect of the increased emphasis placed on the Cat Eye project following the successful flight tests of December 1953 was -- quite typically -- to create funding complications. The ARL budget for Fiscal Year (FY) 1954 had not made provision for an effort on the scale now contemplated, and various planning meetings were held to explore possible solutions. At one such meeting, on 15 January 1954, attended by representatives of both ARL and the Wright Air Development Center (WADC) Directorate of Laboratories, it was decided that Cat Eye research was compatible with current and planned efforts of the WADC Photographic Reconnaissance Laboratory and could "justifiably" be given funds "under any one of several currently approved photographic projects." Moreover, two separate alternatives were available for the funding of the light-amplification work. Either funds up to $100,000 could be made available by substitution of Cat Eye for "some presently planned Photographic Reconnaissance Laboratory work"; or up to $75,000 could be obtained by general reprogramming among that Laboratory's projects. Several weeks later the second alternative was decided upon.[8] Obviously, this short exercise in programming was of no great moment in the long run, but it is one example of the administrative details continually requiring attention.

The sequential light-amplification system was also beginning to interest many individual scientists, scientific organizations, and other government agencies. Although at first large portions of the project were classified, Gebel was repeatedly called upon to present papers to technical and scientific conferences. As often as possible he accepted the invitations, feeling that the communication of the results of his research, if it could interest others, eventually would lead to more work in the area of light amplification and thus shorten the time lapse from research to actual development and production of high-performance image-intensifier systems.

The Redlight Program Conference held at Wright-Patterson Air Force Base on 16-17 February 1954 was attended by representatives of all major

Air Force commands to discuss research and development matters relating to radar, photographic, and optical systems. At this conference Gebel had the opportunity -- through a paper delivered by Dr. John E. Clemens, Chief of the ARL Physics Research Branch to which Gebel was assigned -- to offer a review of his work and arouse the interest of other Air Force commands in light-amplification research. Then, early in April, Gebel himself presented a description of the low-level light meter, which he had designed especially for the Cat Eye project, to the Armed Forces-National Research Council Vision Committee in Washington, D. C. Gebel took advantage of this same trip east to visit the RCA Laboratories at Princeton, for a discussion of light-amplification research efforts and problems.[9]

Gebel's presentation to the Vision Committee brought him a further invitation to attend the Conference on Image Converters sponsored by the United States Bureau of Mines in October 1954. And in 1955 Gebel, Clemens, and associates gave a special demonstration and briefing to the Tactical Air Command in another effort to stimulate more Air Force study and research on the varied aspects and mission applications of light amplification. In general, the response to all these presentations was enthusiastic. Gebel received frequent requests for additional data, from other organizations both in the United States and in foreign countries (e.g., Office of Naval Research, National Research Council of Canada.) Because of the classification problem, it was necessary to withhold certain data from nongovernmental groups, and information was also delayed in being transmitted to other official agencies because of the time consumed in routine security processing. Nevertheless, Gebel and others at ARL spent a great deal of time both in answering requests for information and in briefing visitors who had the necessary security clearance.[10]

ome quarters, a definite "bandwagon effect" was discernible. At least it appeared to Gebel that people occasionally sought to find applications for the sequential light-amplifier system or components in their own work because the Cat Eye project had made that system fashionable rather than for any sound technical reason. One proposal to make

use of the system in another project was bluntly labelled as "idiotic" in the written evaluation drawn up by Gebel.[11] On the other hand, whenever a valid application seemed possible, he was glad to offer what help he could. For example, the WADC Aerial Reconnaissance Laboratory (which had absorbed the Photographic Reconnaissance Laboratory) was supplied with constant up-to-date technical information on the Cat Eye research -- information that supported various efforts to develop "useful [amplifier] devices short of the ultimate."[12] Another development effort involving substantial coordination and exchange of information with Gebel was that of the Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia. The latter organization has properly received wide recognition for its work (principally directed by Mr. Myron W. Klein) in developing image intensifiers along lines similar to those suggested by Gebel in his Cat Eye research.[13]

Funding problems of course continued to be a routine feature of the Cat Eye project, as of nearly all Air Force research activities. However, during the summer of 1955 the climate of the Dayton area led to difficulties of another sort which served to interrupt Gebel's in-house investigations at least temporarily. The hot and humid weather adversely affected temperature-sensitive equipment, and after an unsuccessful attempt to obtain air conditioning for the room in which he housed a breadboard model, Gebel had to resort to his own devices. In order to cool the light-amplifier system including a newly delivered transducer, he used air that was cooled by dry ice and forced over the equipment by 16-inch fans. The attempt failed because of water condensation which damaged the high-voltage section. This caused a breakdown which delayed Gebel's research while he made necessary repairs -- at a time when data on the new transducer were also urgently needed to guide the Westinghouse and RCA contractual efforts.[14]

In the fall of the same year, 1955, certain changes occurred in the personnel associated with the Cat Eye project. In the first place, Dr. Clemens resigned from ARL and accepted a position in private industry. He was succeeded as Chief of the [Engineering] Physics Research Branch

by Dr. Lee Devol, who still heads the unit (which has since evolved into the Solid State Physics Research Branch). Dr. Devol established a very good working relationship both with and among the German and American scientists assigned to his branch, and he gave Gebel wholehearted support on all aspects of Cat Eye. At the same time, he strongly encouraged Gebel to prepare formal technical notes and reports for external consumption. The latter was easier said than done, in the beginning, especially since Gebel's former assistant, Mr. Lake Croft, had left ARL with Dr. Clemens. Gebel thus had to spend a greater amount of his own time in such activities as monitoring contracts. However, early in 1956 Gebel obtained a new research assistant, Mr. Roy Hayslett. The Cat Eye research staff was bolstered further at that time by the addition of a skilled technician and mechanic, Mr. Heinrich A. Bost, and six months later by Mr. Harry Beck, another technician. This increase in staff somewhat relieved (even if it did not entirely end) the manpower shortage that had hampered the Cat Eye program.[15]

A high point in the continuing round of project coordination and presentations was a demonstration of the sequential light-amplifier system on 10 May 1956 at the request of Headquarters Air Research and Development Command (ARDC). The demonstration took place in Baltimore, Maryland, where Headquarters ARDC was then located, and was repeated several times (with a short briefing and discussion on each occasion). It was witnessed by Lieutenant General Thomas S. Power, Commander, and Major General J. W. Sessums, Vice Commander, as well as other senior ARDC officials. General Power was definitely impressed and voiced a number of questions regarding the use of such an apparatus, even though the demonstration had encountered some technical difficulties. Gebel and Devol had requested that an air-conditioned room be provided for the demonstration of the temperature-sensitive equipment; but upon arrival at headquarters on 9 May they found that the room assigned was not air-conditioned. Gebel, Bost, and Hayslett worked through the night to readjust the equipment so as to provide the best possible demonstration under these circumstances. In the end, the performance was still handicapped by the high room temperature, not to mention the lack of a

special lens which was first requested the year before but which still had not been funded and bought. Nevertheless, a fair demonstration was presented.[16]

ARL also continued during 1956 to furnish information to other Air Force commands regarding possible applications of the sequential light-amplifier system in meeting their operational needs. For example, an inquiry was received from the Air Rescue Service of Military Air Transport Service, inspired by mention of the Cat Eye project in a service publication, concerning the suitability of the system for use in rescuing the survivors of aircraft accidents both at sea and ashore. This was without question a legitimate field in which to seek applications, and some highly interesting suggestions were submitted in reply.[17] *

Coordination with other agencies, though always a principal activity of the Cat Eye project, naturally received special emphasis when there appeared to be some chance of obtaining financial or other concrete assistance in return. Such a possibility arose in January 1957 -- and was extremely welcome because of greater-than-usual funding difficulties at that time -- when Dr. Devol received a call from Major Milton M. Berry at the Army Electronic Proving Ground, Fort Huachuca, Arizona, concerning potential applications of the sequential light-amplifier system. During the course of the discussion, Major Berry stated that his organization might have funds available to help support the work of the Cat Eye project, although he did not mention specific amounts.[18] A day or so later, Devol and Mr. Edwin J. Callan telephoned Major Berry from ARL and informed him that $136,000 was urgently needed to support research until the arrival of requested FY-58 funds. Although Berry himself was in no position to commit money, he felt that the chances were good, if the matter was taken up directly with the Commanding General, Army Electronic Proving Ground.[19]

On 6 February 1957 a letter was sent from ARL to the Commanding General of the Proving Ground which reiterated the obvious value of the

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* For a further discussion of the rescue applications, see Appendix A.

sequential light-amplifier system for such purposes as viewing of battle areas on a dark night, explained the present shortage of project funds, and stressed the possibility of a temporary slowdown in Cat Eye work pending the receipt of FY-58 money. The letter also proposed making certain advanced amplifier equipment available to the Proving Ground for experimental use.[20] Unfortunately, nothing came of these negotiations. On 7 March 1957 the Proving Ground made its official reply to ARL:

> The research and development funds available to the Army Electronic Proving Ground for the current Fiscal Year have been completely exhausted. However, due to considerable interest of the Army Electronic Proving Ground on the subject program and in view of the direct application for improvement of Battle Area Surveillance Sensory Devices, it is considered of primary importance that optimum effort be continued if possible.

The Proving Ground therefore took the step of forwarding ARL's letter to the Signal Corps Engineering Laboratories for possible further action.[21]

Another administrative exercise during the first half of 1957 was the formal establishment at ARL of Project 7072, Research on the Quantum Nature of Light, as the vehicle for official documentation of the Cat Eye research effort. Previously, it had been documented as Task 70827, Light Amplification, of Project 6219, Airborne Special Sensors; and this same Task 70827 was carried over into the new project.[22] However, the difference between the titles of the two projects was in itself somewhat significant, reflecting the emphasis on basic-research aspects that Dr. Devol strongly favored in the workload of his branch. To be sure, Devol later expressed some reservations about the exact wording of the new project's title, but he also observed that "the extreme sensitivity of the detection being achieved, down to a few quanta, the fact that the limits on accomplishment now affecting the effort depend on quantum statistics, and the fact that evidence bearing on the fundamental nature of light may actually be found, make it not illogical."[23]

As stated in the project documentation, the objective of Task 70827, Light Amplification, was to "conduct research on the nature of light through the use of opto-electronic methods of amplification which permit

more quantitative studies of fields containing few quanta, and to study phenomena such as photo-emission and luminescence which will permit greater sensitivity and resolution in the conduct of the research."[24] This one task comprised the main Cat Eye research effort, with Mr. Gebel as task scientist. However, Project 7072 also included a Task 70844, "Opto-Electronic Scanning," whose formal objective was to "study theoretically and experimentally the principles of opto-electronic scanning so as to obtain high resolution and instantaneous intelligence transfer between modulated electron currents and modulated photon fluxes."[25] The title of Task 70844 was subsequently changed to "Optical Transducing Processes," with its objective also redefined: "to conduct theoretical and experimental research in electron and solid state physics pertinent to photon detection principles and processes."[26] Task 70844 served, essentially, to supplement the primary task by exploring new basic ideas of possible application not only to the sequential light-amplifier system but also to other image-intensification systems. The research contracts granted under it, though largely initiated by Gebel, were monitored by other members of the ARL staff -- Mr. D. C. Van Sickle, Mr. George Klingler, and Mr. Cole W. Litton.[27]

In the last analysis, of course, administrative questions were less important than the beginning early in 1957 of a program of astronomical observations using the sequential light-amplifier system at the Weaver Observatory of Wittenberg University, Springfield, Ohio. Dr. Lloyd R. Wylie, professor of astronomy at Wittenberg, was hired as a consultant to assist with these experiments, while Wittenberg University furnished its observatory, ten-inch refractive telescope, and other physical facilities without cost to the Air Force. ARL furnished the amplifier system itself and the staff scientists who installed and used the electronic equipment and performed the necessary modification of the telescope. The primary purpose of this collaborative effort was to prove the sensitivity of the equipment by photographing various celestial bodies not only at night time but also during the daytime, taking advantage of the capability of the equipment to detect very small differences in brightness.[28]

A number of photographs were taken at the Wittenberg installation which would not have been possible by conventional photography, especially the daytime recordings. Among other things, a kinescope recording was taken at 1400 hours local time which shows the star Vega as a bright scintillating spot against a black background, instead of its natural dimness against the bright daytime sky. Another recording was of the planet Venus, during a crescent stage, obtained in mid-afternoon with an exposure time of 1/25 second. This picture likewise shows the celestial body as a bright area against a black background, thus demonstrating the remarkable capacity of a system of this kind for background elimination and contrast enhancement.

A high-contrast, mosaic-type picture of the full moon was also produced. Normally, an attempt to obtain details on the moon by photography is made only when the phase of the moon is such as to create shadows, but thanks to contrast enhancement the picture obtained at Wittenberg gives a full-face view showing details over essentially the entire visible surface. Obviously, pictures taken with this kind of instrumentation may some day prove very important for the detection of man-made markings on the surface of the moon.

Although the contributions which the sequential light-amplifier system can make to astronomical research are very great, the experiments at Wittenberg had a direct bearing on other possible uses as well. In particular, Gebel had been giving careful consideration to the role that the system might play in missile tracking, and he regarded the daytime detection of celestial bodies as constituting, up to a point, an exercise in electro-optical acquisition and tracking of missiles -- with Vega and Venus serving as simulated missile bodies.

Interest in tracking capabilities increased sharply in October 1957, after the launching of the first unmanned satellite, Sputnik I. In response to an urgent request from higher Air Force echelons for trajectory data and an inquiry from the Air Technical Intelligence Center as to the possibility of photographing the third-stage rocket of Sputnik I at a high enough resolution to supply data on its size and configuration,

ARL attempted to obtain the desired information with the help of the sequential light-amplifier system. From the outset it was considered unlikely that the satellite could be successfully photographed with the installation at Wittenberg University, because of the very small field of view of the telescope and because the mounting (which was designed for following a star-image course) was too cumbersome for the fast tracking demanded by a satellite. Nevertheless, numerous efforts were made -- without much success -- to track and photograph the satellite using this equipment.

As a more effective means of obtaining the desired information, a new installation was constructed at Wright-Patterson Air Force Base that used a sequential light-amplifier system in conjunction with a suitable telescope on a gun mount having the necessary tracking speed. A powered Navy gun mount was obtained from the Naval Storage Supply Depot at Mechanicsburg, Pennsylvania, and was installed at Wright-Patterson Air Force Base by Mr. D. C. Van Sickle of ARL. Modification of the gun mount and the in-house design and construction of an optical system (as well as of another sequential light-amplifier apparatus) were the responsibility of Mr. George A. Klingler. Dr. Werner Rambauske of the University of Dayton also took part in this undertaking as a consulting astronomer. The equipment was finally put into operation near the end of November 1957.

At first it was expected that the remote-tracking servomechanism, visually operated, would control the mount in the initial stages of tracking and that the human observer on the gun mount would take over control and make the necessary corrections when the satellite came into view of the mount tracking scopes. Later it was discovered that the gun mount could be brought on the target in less time and more surely by a person sighting along the main telescope tube and relaying azimuth and elevation corrections to the trackers by oral command. When the main telescope was brought to bear on the satellite, the image was passed to the transducer photocathode by the proper positioning of a mirror. After the light amplification had taken place, the image appeared on the

monitor screen and was recorded on 16-millimeter motion picture film. At the same time, other motion picture cameras were recording the azimuth and elevation information.

The first really successful satellite photographs made through the use of this apparatus were taken of Sputnik II during predawn conditions on 11 December 1957, at distances ranging from 600 to 758 miles. The original objective was to attain a resolution of 1.35 seconds of arc, sufficient to resolve two objects approximately 17 feet apart at a range of 500 miles. This resolution is the maximum theoretically attainable with the six-inch-diameter objective lens that was used. It was closely approached near the end of the program. However, to achieve this resolution, two modifications of the original system were required. The effective resolution obtained was very sensitive to small changes in the distances between the different lenses of the telescope, with the result that changes in the ambient temperature caused excessive loss of resolution. This trouble was eliminated by providing means for making fine changes in the focusing adjustments under operating conditions. It also proved necessary to match the resolution of the sequential light-amplifier system with the limitation in resolution imposed by air turbulance -- which was achieved by building a new and more highly refined telescope with a sufficiently long focal length. Acquisition tracking, however, was still performed with the original sights of the gun mount.

After the completion of the satellite-tracking program, the tracking station itself was loaned to the University of Dayton. There it was used both for research purposes and for student in-service training programs.

Chapter III

PARTICIPATION OF THE CAT EYE PROJECT IN THE IGY

Even while the astronomical and satellite observations described in the preceding chapter were still underway, preparations had started for another test program involving further evaluation of the sequential light-amplifier system under the auspices of the Smithsonian Astrophysical Observatory. This new program was also intended, at least in the beginning, to form part of the United States cooperative effort in the International Geophysical Year (IGY), which lasted (despite its somewhat misleading title) from 1 July 1957 to 31 December 1958.

The work of the Cat Eye project in the field of image intensification was personally brought to the attention of the Smithsonian by Dr. Lee Devol of the Aeronautical Research Laboratory (ARL) in the summer of 1956. While attending the Congress of the International Astronautical Federation in Rome, Italy, in September 1956, Devol described the sequential light-amplifier system to Dr. Fred L. Whipple, who was Director of the Smithsonian Astrophysical Observatory; and as a result of their discussion, Dr. Whipple made a trip to ARL later in the year for a technical briefing on this amplifier system by Dr. Devol and Mr. R. K. H. Gebel. During his visit an immediate topic of discussion was the possible use of the system to study the planet Mars while it was on a close approach to the earth. Then, after returning to his headquarters in Cambridge, Mass., Whipple wrote to Devol stating that Mars had already moved too far away from its closest approach and that the viewing of another planet should be considered instead.[1] This change in plan eliminated the necessity for rushing the assembly of equipment, as an alternative program of observations could be scheduled to suit the convenience of everyone involved.

Although collaboration between the Smithsonian and ARL was not pushed at this point, at Whipple's suggestion the Air Force Cambridge

Research Center (AFCRC) contacted Devol regarding possible cooperation in certain tests to be conducted in January 1957 at Organ Pass, New Mexico.[2] Although Gebel felt this date to be early, the assembly of all the necessary equipment might still have been accomplished by putting the enterprise on a crash basis. However, nothing came of these discussions.

Contact was not severed with the Smithsonian staff during this period of negotiation with AFCRC. Moreover, during March 1957 a visit to ARL was made by Dr. J. Allen Hynek, who was Associate Director of the Observatory and was also in charge of its planned IGY satellite-tracking operations. Hynek took part in further briefings and discussions concerning the light-amplification research program not only with Gebel and Devol but also with Colonel Nathan L. Krisberg, Chief of ARL, and Mr. Edwin J. Callan, who served in the ARL Operations Office.[3] Later in this visit Dr. Hynek was given a demonstration of the light-amplifier apparatus at Wittenberg University. He was much impressed by the photographs of stars produced at Wittenberg during full daytime brightness and exclaimed, "History is in the making!"[4]

One of the points discussed during Hynek's visit to ARL was the possibility of having the Smithsonian Astrophysical Observatory test the operation of the sequential light-amplifier system. All the parties directly concerned were strongly in favor of such a program; and on 26 March 1957 Dr. Hynek followed through with a letter to Lieutenant General Donald L. Putt, Deputy Chief of Staff for Development at Headquarters United States Air Force (USAF) regarding the possible experimental operation of the light-amplification system under Smithsonian auspices in the forthcoming IGY. The United States had undertaken an earth satellite program (Project Vanguard) as part of its contribution to the IGY and had assigned the Smithsonian Astrophysical Observatory primary responsibility for optical tracking of the satellite. Smithsonian officials divided their program into two phases: precision optical tracking by means of f/1 Schmidt telescopic cameras stationed at twelve points around the globe, and the lower-precision effort of tracking by teams of volunteer visual observers in Operation Moonwatch. As

Hynek observed to General Putt,

> In our precision program, we have had to resort to standard optical photographic methods as offering the surest method consistent with the demands of accuracy. At the time our decision was made, we had considered possible electronic means of satellite tracking, but because of the pressure of time and the developmental work yet necessary on electronic methods, we decided upon tracking the satellite by photography despite certain severe limitations that this method imposes.

Hynek stated further that the "immediate program" of precision tracking had already been "frozen to meet the needs of the first satellite." Nevertheless, Hynek urged General Putt to establish a cooperative link between ARL and the Smithsonian Astrophysical Observatory, noting that "the developments at [ARL] hold such promise for the problem of the detection of extremely faint objects . . . that we would be remiss in our scientific obligations to the satellite program and the field of astronomy if we did not explore the possibility of joining our resources with yours in this research, to our mutual advantage."

More specifically, Dr. Hynek proposed that one complete light-amplification system be installed at one of the 12 precision tracking stations, so that the Smithsonian staff could "evaluate the potentialities of the apparatus for purposes of tracking satellites and other faint objects and explore the potentialities of this new development for other problems, notably of astronomical and astrophysical character." The Smithsonian would primarily offer the services of its staff, who were highly trained in astronomical investigations, once the system was installed. Dr. Hynek told General Putt that the Smithsonian budget for the IGY program was limited and that

> . . . if it were possible on our present budget to support completely the equipment development program we would not hesitate to do so. Our present budget, however, precludes the expenditures necessary for the purchase and fabrication of basic electronic equipment, which I am led to believe would amount to approximately $100,000. Our transfer fund could not exceed $10,000 this year.[5]

Although General Putt was very enthusiastic over the possibility of testing the light-amplification apparatus in the hands of the Smithsonian

scientists, his 11 April 1957 reply to Dr. Hynek was necessarily non-committal. He did assure Hynek, however, that "a cooperative effort with regard to electronic-optical equipment for use in the Scientific Satellite Optical Tracking Program is receiving serious consideration . . . . [and] that the desirability and value of the precise tracking of the scientific satellite is recognized in the Air Force."[6] General Putt then forwarded Dr. Hynek's letter to the appropriate Air Force command -- specifically to the Commander, Air Research and Development Command (ARDC) -- observing that the objective "appears to offer the Air Force a good opportunity to obtain an expert evaluation of techniques and equipment potentially useful in this new but important field, and it is believed that Dr. Hynek's proposal merits your serious consideration."[7]

At Headquarters ARDC the task fell to Brigadier General Marvin C. Demler, Deputy Commander for Research and Development, to investigate the possibility of fulfilling Dr. Hynek's request at his command level. General Demler informed General Putt on 29 April 1957 that he believed the time was appropriate for the intensification of research efforts on light amplification and the evaluation of its potential in detecting and tracking satellites and other faint celestial objects. General Demler believed that

> . . . this proposed cooperative program offers the Air Force an excellent opportunity to obtain the services of highly qualified scientists engaged in the evaluation of light amplification equipment at a small fraction of the normal cost. Furthermore, the possibility of obtaining the services of such a highly qualified group through other sources is doubtful, regardless of cost.

As to the funding of such a program, General Demler maintained somewhat less optimistic views. Headquarters ARDC did not have the resources immediately available to supply ARL with the $100,000 deemed necessary for the entire assembly; it did, however, transfer $30,000 from ARDC's Quick Reaction Funds for procurement of two specially made transducers. These items required the longest lead-time and would have to be ordered at once if the Air Force were to meet the schedule of the Smithsonian

and of the IGY. General Demler informed General Putt that ARDC intended to submit "the remaining $70,000 requirement . . . to Headquarters USAF as a high priority item to be included in the FY [Fiscal Year] 1958 Advanced Buying Program of the 171 Service Test Budget." Demler anticipated that these funds would be available early in FY 1958 and that procurement of the complete apparatus could thus be time-phased effectively with the fabrication of the special transducers.[8]

On 29 April General Demler also notified Dr. Hynek officially that the Air Force was now committed to his proposal for cooperation. General Demler mentioned in his letter to Hynek that the proposal was very timely, fitting in well with the current status and progress of the Cat Eye project, and that the Smithsonian staff would be provided with the most advanced light-amplification equipment available to the Air Force. Hynek was informed of the current funding problems and of the recent transfer of $30,000 for long-lead-time procurement, and General Demler added optimistically that the remaining $70,000 should become available "shortly after 1 July 1957."[9]

Naturally, this decision was the outcome of some very extensive consultation and coordination among different Air Force echelons. Headquarters ARDC, on its part, was well aware of the Hynek proposal before General Putt forwarded Hynek's letter to General Demler and at first had endeavored to have ARL absorb the additional costs involved. But when Headquarters USAF telephoned Colonel Krisberg on 4 April 1957 to see if ARL's financial situation could absorb the $100,000 in additional work, Krisberg replied that ARL simply did not have the necessary resources and that it would fall to Headquarters USAF and ARDC to manage the funding of the $100,000.[10] Colonel Krisberg and Lieutenant Colonel Robert G. Ellis, Assistant Chief of ARL, further discussed the situation with Drs. Devol, Hynek, and Whipple on 19 April. Their discussion confirmed the earlier estimate that $100,000 would be absolutely necessary for the equipment. It was estimated that the money would be used as follows: two two-stage transducers costing $15,000 each, which were the long-lead-time items and would constitute an intensifier

image orthicon transducer system capable of a total gain of one billion times; a storage unit with iatron storage tube costing $25,000, to permit integration of successive scanned frames; a five-inch lens system (long focal length) at $15,000, which would match the intensifier transducer face resolution to provide undistorted imaging; and a moderately sophisticated electronic chain and assembly costing $30,000. Funding questions were then discussed in greater detail by Colonel Ellis and Mr. Callan of ARL and Captain Patrick H. Caulfield of the Plans and Programs Division, ARDC Directorate of Research. Since funds had not been found in the Wright Air Development Center (WADC) research program to expedite purchase of the long-lead-time transducers, Captain Caulfield stated that he would try for quick-reaction funding but could not guarantee the amount. He also asked Callan if it would be possible to use the $10,000 pledged by Dr. Hynek to help with transducer procurement, since the ARDC Quick Reaction Funds were nearly exhausted. Callan agreed to check with Hynek but noted that the Smithsonian group was primarily concerned with the "optics aspects" of the collaborative program and might already have earmarked the funds for other equipment. A Service Test Requirement was determined to be the best approach to obtain the remaining items, and Captain Caulfield suggested that Master Sergeant (later Chief Master Sergeant) Edmund T. Tyson, Jr., of the Aerial Reconnaissance Laboratory, WADC, should aid in drafting the necessary paperwork.[11]

Callan also carefully investigated the possibility of assembling the equipment in Air Force shops at Wright-Patterson Air Force Base. However, this expedient would also have required some additional funding, not to mention the Air Force manpower involved. Hence there was some doubt that the local shops could handle the job, and the idea of in-house assembly was abandoned.[12]

On 24 April 1957 Captain Caulfield telephoned Callan to state that a TWX was being sent to WADC transferring $30,000 in ARDC's Quick Reaction Funds to purchase the two transducers. Caulfield mentioned further that certain preliminary steps had been taken to obtain approval

of Headquarters USAF for the other $70,000 in equipment expenditures under the proposed Service Test Requirement.[13]

Now at last the funding question seemed on the way to solution. At this point Lieutenant General Thomas S. Power, Commander of ARDC, was given a briefing (25 April 1957) as to the current status of the proposed collaboration between the Smithsonian and the Cat Eye project by General Demler and Colonel Leslie B. Williams, ARDC Director of Research. Dr. Hynek was similarly briefed by Edwin Callan, and Callan noted that Hynek was pleased by the expeditious handling of affairs.[14]

Also on 25 April, Major Walter Sanders of the Directorate of Research, Headquarters ARDC, telephoned Colonel Ellis to relay a suggestion that the Bendix Friez Lumicon chain (with standard image orthicon and conventional circuitry) be used as a substitute for the more expensive sequential light-amplifier system with the special transducers and more sophisticated circuitry--a move that Colonel Ellis promptly disapproved because it would not provide the extreme sensitivity necessary for evaluation. Secondly, Major Sanders inquired if it would be possible for ARL to await FY 1958 funds, although he did mention that there was still a possibility of obtaining some FY 1957 funds if absolutely essential. Colonel Ellis agreed to inform Headquarters ARDC what funds would be currently needed and what expenditures could be postponed until the arrival of FY 1958 funds.[15]

Drs. Whipple and Hynek telephoned ARL on 26 April to discuss the proposed collaborative program in some detail with Colonel Ellis and Dr. Devol and also to suggest still another joint operation. Whipple, in particular, was extremely enthusiastic about the possibility of mounting a light amplifier and good optical system on a stable platform and then taking the platform to high altitude by means of an airplane or balloon so that observations could be made with less atmospheric interference. It was agreed that Dr. Devol would meet in Boston a week later with Hynek and Whipple in order to explore this new proposal further as well as to discuss technical and other arrangements for the

entire joint program. Meanwhile, it was decided that the business aspects could best be handled by negotiating a dollar-a-year contract between the Air Force and the Smithsonian Astrophysical Observatory. This would, among other things, facilitate the transfer of Air Force material and equipment.[16]

On 26 April a telephone call was made to Headquarters ARDC in answer to the previous call from Major Sanders and pointing out that if the time schedule presently established for Project Vanguard were to be met it would be impossible to await FY 1958 funds for the entire project. Colonel Ellis said that a maximum of $70,000 could be awaited from FY 1958 funds, but the $30,000 for the two transducers of nine months lead-time must be forthcoming immediately. Although Captain Caulfield had mentioned two days earlier that $30,000 from Quick Reaction Funds was being transferred by ARDC, written notification had not arrived at ARL, and purchasing was being delayed. The $15,000 lens, the storage reproducer costing $25,000, and the remaining parts had only a six-month lead-time and would properly phase with FY 1958 funding. Colonel Ellis stated that the transducers would be procured through RCA, the storage reproducer would be contracted with the Farnsworth Electronic Company of Fort Wayne, Indiana, because of their particular capability in this field, and the lens and other components would be on open bid.[17]

The $30,000 did finally arrive. Colonel Leslie B. Williams, as ARDC Director of Research, then urged WADC on 1 May to expedite the procurement of nine-month-lead-time transducer fabrication for which the funds had been specifically earmarked. Williams stated that the transferred funds must be obligated by 20 June 1957 and urged the amending of the current contracts with RCA to cover this fabrication.[18]

Although there was less urgency in obtaining the other necessary items--those that could wait for FY 1958 money to become available--the written Service Test Requirement was completed as of 9 May 1957 and was forwarded from Headquarters ARDC to Headquarters USAF on 13 May. It called for funds to obtain all the needed components except the special transducers--which were being ordered separately--and to assemble

the complete apparatus. According to the Service Test Requirement, the final assembly could be performed by Westinghouse, Philco, or RCA. In view of the Air Force policy of not ordering new equipment when operational equipment is available, it was carefully noted that this apparatus would replace no equipment in current use. The Service Test Requirement was specifically submitted for BP-264 (centrally-procured photographic equipment) funding.[19]

A few days later word was received at Headquarters ARDC that the $71,050 requested -- i.e., $70,000 plus $1,050 for transportation of the assembly -- had been disapproved under the BP-264 budget area but had been approved for the BP-690 (research management and support) area. The approval in the latter category was due, in part, to the efforts of Sergeant Tyson, who had personally carried the required BP-690 paperwork to Headquarters ARDC after it became apparent that funding would not be approved in the BP-264 budget area.[20] The ARDC BP-690 budget ceiling for FY 1958 was raised by Headquarters USAF to cover this expenditure. However, Headquarters USAF had merely given oral notification of its decision, and nothing further could be done for the moment.[21]

This matter was not finally settled until well after the start of the new fiscal year. In what was intended as a signal to proceed at once with the necessary procurement actions, Colonel Williams notified WADC by TWX on 26 July 1957 that the light-amplifier assembly had been added to the Air Force "approved buying list" in the BP-690 fund category. Pointing out that the Smithsonian had been given positive assurance that the equipment would be available, he urged that the procurement be expedited so as to provide sufficient time for operational checkout. At the very end of his message, Williams took note of the fact that BP-690 funds were "at present suffering certain restrictions;" but he gave no indication that he regarded the funding situation as an insuperable obstacle to carrying through the ARL-Smithsonian joint endeavor.[22]

Actually, some rather serious funding complications had arisen. On 25 July, the day before Colonel Williams' TWX was sent, Captain Marvin B. Sullivan of Williams' Directorate had telephoned Colonel Ellis

at ARL stating that the promised $70,000 would be placed in the WADC BP-690 program but that the money would not be earmarked specifically for ARL or for the amplifier assembly. Moreover, FY 1958 had started out with an Air Force-wide austerity drive that did not really taper off until after the launching of Sputnik I on 4 October. Thus WADC, like most other Air Force elements, was faced just now with a firm requirement to carry out across-the-board cuts in its expenditures. Project Cat Eye, in effect, would have to compete for the $70,000 with numerous other WADC research and development projects that were seeking desperately for some relief from austerity-drive retrenchments. As a basic research effort, Cat Eye was in a poor competitive position as compared with other projects directly supporting high-priority weapon systems;* and as Sullivan explained in his call to Colonel Ellis, if WADC found it impossible to give ARL the $70,000 to support the joint program, then the latter must be cancelled at least temporarily and the situation presented to Headquarters USAF for further consideration.[23]

Unfortunately, but not surprisingly, WADC felt unable under the circumstances to support the program. A TWX of 12 August 1957, answering the one sent to WADC by Colonel Williams on 26 July, stated that the BP-690 funds

> . . . assigned to this Center are not sufficient to procure approved but unfunded items such as the light amplifier assembly. . . Present BP-690 funds are insufficient to procure those support items required for the highest priority projects. In the event of receipt of additional BP-690 funds, procurement of the amplifier assembly can be initiated immediately. However, to avoid future contractual delays it is suggested that commitment availability be secured and furnished simultaneously with funds.

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* This same funding situation naturally affected other aspects of the Cat Eye project. For a time both RCA and Westinghouse continued certain contractual research efforts without funding, in the well-founded expectation that funds would become available later on; but they naturally did so at a lower level, and some time was lost. In-house efforts were likewise curtailed, again with loss of valuable time.

The TWX further suggested that the funds be made available by 15 September 1957 to allow enough time for both procurement and checkout.[24]

Major General J. W. Sessums, Jr., ARDC Vice Commander, wrote to the Commander of WADC, Major General Thomas L. Bryan, Jr., on 23 August 1957 reflecting deep interest in providing the light-amplifier assembly as a form of Air Force participation in the IGY. Sessums emphasized that General Putt had personally enjoined ARDC to cooperate with the Smithsonian in this undertaking and recalled the subsequent action of the command in parting with rather scarce Quick Reaction Funds to procure long-lead-time items. "I am certainly cognizant of the budget restrictions which place you in your present predicament," General Sessums told General Bryan, and he stated that he was

> . . . also aware that Project 7072 does not carry a priority rating, which is a necessary characteristic of all projects in the Research Program area. However, I cannot help but feel that this effort may not be understood by your people in the proper perspective regarding its importance to the Air Force. The proposed cooperative program offers the Air Force an excellent opportunity to obtain the services of highly qualified scientists in the evaluation of light amplification techniques under conditions which we may not be able to duplicate for many years to come. . . The additional embarrassment which will accompany any Air Force attempts to pull out of this endeavor after making initial commitments is another factor which must be heavily considered.

In conclusion, General Sessums urged General Bryan to accomplish the $70,000 procurement if at all possible with BP-690 funds already on hand; he did not offer additional funding.[25]

Colonel Harvey P. Huglin, who had temporarily assumed command of WADC, replied to General Sessums on 30 August stating that WADC officials had been deeply concerned with this problem for the past several months and fully recognized the potential value of the collaborative effort with the Smithsonian. However, he reminded General Sessums that the BP-690 funding situation had deteriorated seriously and that the Center was currently "short of $800,000 of payroll funds under the most optimistic of conditions." Colonel Huglin thus could not offer much hope regarding the $70,000 for the light-amplifier assembly. Huglin assured General Sessums that he would do his best to locate an

item which could be eliminated from the WADC BP-690 area and whose elimination would "do less harm than the elimination of the Cat Eye [test] program;" but in closing he added pessimistically, "At the moment, we frankly do not know where the money will be obtained."[26]

When Huglin's message reached Headquarters ARDC, it was routed to at least three general officers (including Sessums) and naturally passed through the hands of numerous lower-ranking officials as well. The resulting comments ranged from an exhortation to "bend every effort" to fulfill the Air Force's moral obligation to a suggestion that some other agency be found that would "pick up the tab for the test and application to IGY."[27] It would be pointless at this late date to try to track down all the phone calls and other exchanges that may have taken place in a final effort to save the proposed test program. One can only say that somehow, at the last minute, WADC itself agreed to "pick up the tab."

On 12 September 1957, in effect, Colonel Huglin notified General Sessums that a $70,000 purchase request had been prepared and was being processed through procurement channels on the basis of WADC BP-690 funding. The Industrial Electronic Products Division of RCA, which qualified as the sole source for assembly of the equipment, signed the official contract in February 1958, and the desired delivery date was placed nine months thence. The contracting was initially handled by Edwin Callan and later by Sergeant Tyson, who was the choice of both Callan and Gebel for supervision of the cooperative work with the Smithsonian Astrophysical Observatory.[28]

Once the question of funding was solved and the necesary procurement actions initiated, the next problem was to select a location for the apparatus. Three separate locations were considered in this connection: West Palm Beach, Florida; Organ Pass, New Mexico; and a site in Hawaii. Sergeant Tyson and Dr. Devol preferred the Florida location for a number of reasons that included ready accessibility of an RCA service organization, superior electrical service, and in general (they felt) the greatest ease and reliability of operation. The New Mexico site was on the edge of the White Sands Missile Range and thus offered

excellent opportunities to test the amplifier system in acquisition and tracking of guided missiles. The Hawaiian site was not considered very seriously because of the distance involved both for personal travel and for the shipping of equipment; while from the standpoint of logistics Florida and New Mexico were about equally suitable. In the end, Organ Pass was chosen -- which was the preference of Dr. Hynek.[29]

The Smithsonian Astrophysical Observatory undertook to prepare the site itself, once the latter had been selected. The Smithsonian had already allocated part of its initially pledged $10,000 contribution to the purchase of a $7500 lens. It spent the remainder in providing a building at Organ Pass that was 13 feet square, with an eight-foot pier and with an eight-foot-square astrodome erected on the roof. Two Smithsonian staff members -- Mr. Charles Tougas and Mr. George G. Barton -- were engaged in the design and construction of the necessary observatory facilities at the Organ Pass site. Barton, who was the Smithsonian observer, had earlier obtained considerable technical orientation from Gebel and his team at the Wittenberg installation to familiarize himself with the sequential light-amplifier system. Also, he received extensive technical instruction from Sergeant Tyson when the latter arrived on the scene in December 1958. The light-amplifier electronic equipment reached nearby Holloman Air Force Base in October 1958 but was not installed at Organ Pass until RCA engineers arrived to accomplish the final assembly and preliminary testing. The system was attached to a Perkin-Elmer ten-inch cadioptric Schmidt telescopic apparatus. Further modifications and adjustments were made by Tyson himself after his arrival; he then accepted the equipment from the contractor.[30]

During Tyson's December visit to the Organ Pass site, he urged that the investigation of signal-to-noise improvement and increase in sensitivity by integration-pulse methods be made a part of the program. When he later returned to Organ Pass, he supplied the necessary additional equipment for this purpose, and the use of time-integration methods proved to be quite successful.

Also at the time of Sergeant Tyson's December visit, the people at Organ Pass were having difficulties with transducer sensitivity. The transducers procured from RCA later proved to have minute cracks in the glass which resulted in deterioration of the vacuum, thus decreasing both the life of the transducers and the effective sensitivity. RCA made numerous attempts to correct the situation and was finally successful; but it was then too late to affect this test program. However, Tyson had also brought a General Electric (GE) thin-film target image orthicon to the site for test and evaluation. This GE transducer proved to have a much longer life span, and, when the results were transmitted to Dr. Hynek, he obtained the loan of another of the GE transducers expressly for use in the Organ Pass observations. Thus the GE transducers were used to produce most of the data, ultimately providing useable information to 9.5 apparent magnitude when operated at normal frame-reproduction rates. When integration techniques were used, it was possible to reach 13.5 magnitude easily and 15.5 magnitude under special conditions.[31]

Unfortunately, the Organ Pass installation was not well suited for the fast tracking required in satellite observations. Thus, despite some early attempts, no major effort was made by the Smithsonian to photograph satellites; stellar observations became the principal activity, and some very interesting data were obtained.[32] To be sure, in view of the problems with the ultrasensitive RCA transducers, the tests were not really able to demonstrate the full potential of the sequential light-amplifier system. Nor did this joint effort of ARL and the Smithsonian Astrophysical Observatory quite live up to its advance billing as a form of United States participation in the IGY. Principally because of the funding delays, the Organ Pass installation was not fully prepared and accepted until the last month of the 18-month IGY, although naturally the test program received various extensions to compensate for its late beginning.[33]

It is worth noting in conclusion that for better testing of the sequential light-amplifier system Sergeant Tyson and co-workers from

his own laboratory set up an installation at Sulphur Grove, Ohio, not far from Wright-Patterson Air Force Base. The optical mount used for this installation is highly mobile and adaptable and can serve either for stellar observations or for tracking of fast-moving satellites. The Cat Eye project and ARL were not directly involved in this effort, although Gebel loaned Tyson a 20-inch reflective optical system, built under ARL contract by the Oude Delft Optical Company in the Netherlands, for use at the Sulphur Grove installation. Some remarkable kinescope recordings of satellites have been obtained, demonstrating nearly perfect tracking. The transducers used in these tests had only modest sensitivity; but comparable recordings would have been impossible by conventional methods.[34]

Chapter IV

PROJECT ADMINISTRATION AND RESEARCH, 1958 TO TERMINATION

At the end of 1957, after more than five years of research, the Cat Eye project had achieved a scene-brightness detection threshold of 10^{-8} foot-lambert, and the viewing screen reproduced the intensified image with daylight brightness. The sensitivity threshold was 100 times that of the human eye and 10,000 times that of highly sensitive grades of photographic film; while for detecting moving targets the scene background could be substantially eliminated by a background compensator.[1] Both the project scientist, Mr. R. K. H. Gebel, and Dr. Lee Devol, his branch chief and a strong supporter of the Cat Eye program, believed that the research results obtained so far could already be considered as a basis for extensive technical development. But they were equally convinced that additional research still needed to be done.[2]

The research program continued to be divided mainly between Gebel's own in-house efforts at the Aeronautical Research Laboratory (ARL) and the contractual efforts of RCA and Westinghouse. The two contractor firms received various new and renewed contract awards during the period 1958-1959, basically along the same lines as their former work but with certain changes in scope or emphasis. For example, one contract awarded at this stage to RCA was designed to support research by Dr. Paul K. Weimer on isocon-scan techniques, which offered special promise for satellite applications. This was work Gebel had wanted to press before, but which actually got underway only in 1958.[3]

Meanwhile, as in previous years, ARL staff members associated with the Cat Eye project were spending a large amount of time in coordination and discussion of research progress with the various technical development laboratories of Wright Air Development Center (WADC) and with other research and development organizations. Substantial design information

and performance results were provided to those who had use for them. Image intensification was discussed in detail with (among others) scientists of the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, where an acquisition system consisting of 25 sequential light amplifiers working at once side by side was eventually developed under the principal direction of Mr. Walter E. Woehl. This system bore the special designation of Facet Eye.[4] Also during this period, exchange of information within the Air Force in the field of light amplification was fostered by a general research coordination meeting held at the Air Force Cambridge Research Center (AFCRC) in October 1958. In addition to AFCRC and ARL, the participants included other components of WADC and of the Air Research and Development Command. The meeting conducted a review of Air Force projects and tasks in this and other research areas;[5] and it was followed a few weeks later by an interservice meeting on camera-tube development held at Wright-Patterson Air Force Base.[6]

Another continuing aspect of project activities was the presentation of public demonstrations and scientific papers. Appropriately, Cat Eye was one of the projects featured at the formal dedication of the present ARL laboratory building, on 2 May 1958. In addition to other displays illustrating the work of the project, the previously mentioned background-compensation capability was successfully demonstrated by showing a circling model aircraft on the reproducer screen which simply disappeared when it stopped even though it still remained in the field of view.

Then, too, on invitation by the Imperial College of Science and Technology of the University of London, a paper by Gebel and Devol entitled "Some Early Trials of Astronomical Photography by Television Methods" was read by Dr. Devol at the Symposium on Photoelectric Image Devices as Aids to Scientific Observation which was held in London in September 1958. This paper was accompanied by pictures illustrating the advantages of the sequential light-amplifier system. Dr. George A. Morton, one of the RCA scientists working under contract with ARL on

the project, also gave a paper at the London symposium concerning the performance of the special transducers produced at the RCA Laboratories in Princeton.[8] Both papers were later published in the series Advances in Electronics and Electron Physics (Volume XII) and contributed to wider scientific recognition of the project accomplishments, as did a paper by Gebel on the Wittenberg experiments in daytime detection of celestial bodies, which was presented before the Army Engineer Research and Development Laboratories symposium on image intensifiers in October 1958. The latter paper was also published in the symposium proceedings.[9]

On a slightly more popular level, an article in Science News Letter for 16 August 1958 featured the Cat Eye research and in turn attracted the interest of Sky and Telescope, which requested that an article relating to the project be written for publication in a forthcoming issue. Gebel collaborated with Professor Lloyd Wylie in producing the desired article; it appeared in December 1958.[10] Two other magazines also showed an interest in Cat Eye at this time. Wingspread publicized the ARL research accomplishments in its September 1958 issue, and Missiles and Rockets included the article "Camera Pick-up Tube Heart of New Telescope" in its 1 December 1958 issue.

During much of 1959 the administrative story of the Cat Eye project centered around planning and negotiations for the transfer of management responsibility from the research area to technical development, which was largely accomplished before the end of the year. First, however, it is well to mention one more of the various examples of successful test and evaluation of sequential light-amplifier techniques of the type investigated in Gebel's Cat Eye research. ARL had nothing directly to do with the test series in question, which took place in Florida during the fall of 1959 in connection with the so-called RCA Missile Test Project; but one of the principal figures was Senior Master Sergeant (later Chief Master Sergeant) Edmund T. Tyson of WADC's Aerial Reconnaissance Laboratory, who had previously collaborated with Gebel and ARL in the Smithsonian test program.

The Florida tests were begun at a point 15 miles from Cape Canaveral but were later relocated at a distance of 55 miles. A 90-millimeter

anti-aircraft gun mount served as mounting for a long-focal-length optical telescope system, which was used with a variety of image orthicons and other electronic components personally brought from Wright-Patterson Air Force Base by Sergeant Tyson. Missile count-down information from Canaveral was relayed over the standard range communications and timing network, thus making it possible to record both day and night missile events when atmospheric conditions were favorable. Recordings of orbiting satellites were also sought, but the visual sightings were too brief to permit optical acquisiton with the equipment at hand; hence no satellite recordings were obtained.

These tests underscored several important advantages of the system used. The possibility of obtaining a contrast-enhanced image instantaneously on the reproducer was a primary asset, and the viewer could electronically control the scene-brightness and contrast-enhancement characteristics. Adjustments could be made immediately, whereas in a conventional photographic system the need for them may not be apparent until after the film is developed. The short exposure times made possible by the system's high sensitivity permitted unusually detailed recordings of the rocket exhaust plume during a missile flight. Also, daytime tests aided in proving the capabilities of this type of light-amplifier equipment where considerable difficulties exist for conventional photography because of adjacent sky brightness. Tests were conducted during daylight hours in order to record details of the missile surface and attitude along with a rendition of the exhaust plume to show burning characteristics; of particular interest were missile staging phenomena and nose-cone separation in late flight. Naturally, the "selected image orthicon television system" used in these tests also had certain limitations; but the final report strongly urged that such a system be obtained for operational use at the Atlantic Missile Range, noting that in the recent experiments it had displayed "over one thousand times the sensitivity of our fastest photographic systems presently employed on long focal length tracking telescopes."[11]

* * * * * *

By the close of these Florida tests, ARL's Task 70827, Light Amplification -- constituting the main Cat Eye research effort--had been officially terminated, and work still in progress under that task had been transferred to the jurisdiction of the WADC Electronic Technology Laboratory (ETL).* These moves meant that the results from Cat Eye were now offically regarded as ready for technical development -- an outcome that duly attested to the success of what had begun years before as a research project. Nor was technical development based on this research anything really new. Gebel had warmly encouraged such efforts all along, and in the WADC budget for Fiscal Year (FY) 1959 there were funds expressly allotted both for Cat Eye research and for related technical development.[12]

And yet neither Gebel nor Devol felt wholly satisfied with the final disposition that was made of the Cat Eye project. To begin with, they felt quite strongly regarding the need to continue basic research in the field of light amplification alongside technical development of promising applications. In a report of December 1958 submitted to Col. Eugene C. Mallary, Chief of ARL, Devol had observed that only a "temporary plateau" had been reached in the Cat Eye research effort and that "we are now . . . reconnoitering much higher peaks."

Devol considered research on the nature, character, and origin of dark-current emission and the study of bombardment-induced conductivity in semiconductors to be desirable basic research. In this category he also included research on electroluminescent materials, investigation of reported photomagnetic effects, and basic research in the area of coherent light (including its generation and detection). It was not possible to project the exact operational benefits from any one of these studies, but Devol observed that the entire field of solid state physics was in a rapid state of development and that the areas under consideration were not being adequately covered. Moreover, he felt that technical

* Until 12 June 1959 ETL was officially known as the Electronic Components Laboratory, but for convenience it will be cited as Electronic Technology Laboratory (ETL) throughout this study -- even in cases where the events referred to actually took place before 12 June 1959.

development work planned on the basis of knowledge thus far acquired, while showing great military potential, fell far short of the ultimate that could be achieved through further basic research.[13]

It followed almost inevitably from this thesis of the great importance of continued basic research that such research should be left at least a little longer in the hands of the team that was most familiar with it: namely, that headed by R. K. H. Gebel of ARL. On the other hand, there were obviously some people at higher echelons who suspected that both Gebel and Devol were being unduly possessive toward the Cat Eye project and that Gebel, having effectively fulfilled the role of trail-blazer in the field of low-light-level image intensification, could now use his time more productively by turning to some new endeavor. Actually, of course, Gebel had never intended to keep working on Cat Eye indefinitely; from his standpoint, the question was partly one of timing and partly one of wanting to be sure that whoever inherited his responsibilities also shared his enthusiasm. In any case, the final decision was to make a clean break, at least organizationally: to turn the entire Cat Eye project as it existed at ARL over to the control of ETL (with certain minor exceptions). ETL could then pursue further research and technical development in the area as it saw fit, though presumably with far greater stress on technical development.[14]

The transfer of work from ARL to ETL naturally did not take place from one day to the next but rather took place by stages over the second half of 1959 (or first half of FY 1960). In all the planning and preparations leading up to the change, moreover, numerous complications had to be dealt with. Thus while ETL expressed definite interest in pursuing technical development work arising from the research performed by Gebel and his team in the Cat Eye project, it also pleaded inability to accept additional responsibilities without assignment of additional personnel. In order to meet this problem, Mr. Edwin Callan of ARL proposed at a meeting held in May 1959 that the work to be taken over by ETL should be placed in one of that laboratory's technical development projects but monitored by ARL staff members (Gebel in particular) until

such time as ETL personnel were prepared to assume direction of it. This solution seemed to satisfy the positions of both ARL and ETL, although Dr. Devol was careful to point out that he did not want his branch to become indefinitely involved in technical development work.

Several important questions regarding the future status of the Cat Eye project still had not been clearly resolved at this early stage. Nevertheless, ARL was directed on 18 June 1959 to transfer three research contracts which were due to expire during FY 1960 to ETL by 1 July. These contracts included the RCA contract for studies of isocon-scan techniques under Dr. Paul K. Weimer and two Westinghouse contracts. At the same time, ARL was directed to terminate the basic RCA contract for research on sensitive imaging techniques under Dr. George Morton upon its scheduled expiration date early in the new fiscal year. This last decision was made despite a consensus previously reached at a conference with WADC legal and patent personnel to the effect that the contract should be continued by ARL (at a reduced rate) with FY 60 funds, for reasons involving protection of government rights to certain patents and technical information.[15]

In August 1959 a special meeting was held concerning the Cat Eye transfer with Major Joseph M. Leone from Headquarters Air Research and Development Command (ARDC) in attendance, as well as representatives of ETL and ARL. It was now fairly apparent that all work in progress under Task 70827 was to be transferred away from ARL unless terminated sooner, and the monitorship of contractual efforts that were to be transferred from one laboratory to another therefore came up again for detailed discussion. ARL argued that Gebel should continue as contract monitor, even after administrative responsibility for the work was transferred, until the conclusion of existing contracts -- thus essentially maintaining a stand ARL had taken earlier. One advantage of such a solution (frankly stressed by Dr. Devol) was that it would permit the final reports on work supported by the contracts to be published under the auspices of Gebel and ARL, correctly reflecting the share of credit that they deserved. The meeting adjourned without a firm decision on

this matter, but an ETL representative seemingly gave tacit acceptance to at least some continuation of Gebel's monitorship beyond the date of effective transfer from ARL to ETL.[16]

Shortly after this meeting, Dr. Devol left for Stockholm, Sweden, to attend the Fifth Conference of the International Commission for Optics. On 28 August he delivered a paper, which he had co-authored with Gebel, on "Limiting Sensitivity of Optical Amplifying Equipment." (A revised version of this paper was later published in the German scientific journal Zeitschrift für Instrumentkunde.)[17] On his return to the United States, Devol was soon involved once more in the Cat Eye project negotiations. Both ETL and Headquarters ARDC were now increasingly anxious to complete the transfer of work, and, despite the previous discussion of such a possibility, there was little disposition to let Gebel continue monitoring contracts after the transfer was completed. Under these circumstances, Devol insisted that at least some proper acknowledgement be accorded Gebel and ARL when the final reports covering results of contract work were published under other auspices.[18]

It also became necessary to reach some decision as to the disposition of experimental transducers that were being produced under existing contracts. Some 14 transducers were involved, of which ARL required -- and was now promised -- an absolute minimum of three for research purposes: two that were vital to research programs being coordinated by ARL with other agencies, and a third that was needed for in-house work.[19]

By November 1959 the transfer of work conducted under ARL's Task 70827, Light Amplification, was complete, and a statement of termination was issued. The official reason for termination of the task was given as follows:

> The major efforts under this task have progressed from basic research into what is properly the responsibility of applied research laboratories. Consultation between members of this Laboratory [ARL], representatives of other Center Laboratories, and Headquarters ARDC served to determine the proper location for future development efforts. The termination of the Aeronautical Research Laboratory's efforts under this task will release personnel, equipment and funds for utilization in other basic research efforts....Technical development has been started by the

> Electronic Technology Laboratory, with the objective of developing an optical amplifying transducer utilizing the most advanced results of this task.[20]

The statement of termination listed the task as being 75 percent completed, noting that "some additional basic research will most likely be necessary to support the most effective development program." ARL planned to reassign personnel to a new project dealing with semiconductors, and Task 70827 equipment which could be used in this new research was retained by ARL. It should be noted that Gebel and Devol expected basic research on semiconductors to be, among other things, a fruitful source of new ideas to advance the state of the art of optical amplification, and that contracts in this area had been a part of the Cat Eye project. In a final review of research accomplishments under Task 70827, it was determined that a total of 30.1 man-years had been expended, along with $1,039,111 in BP 610-680 (contractual research) funds and $185,666 in BP-690 (research management and support) funds.

With the formal transfer of research activities, Mr. Melvin R. St. John of ETL became monitor of two RCA and three Westinghouse contracts which had formed part of the Cat Eye effort. These were now assigned to ETL's Project 4156, Thermionic and Solid State Electronic Technology, Task 41653, Special Tubes. The WADC Aerial Reconnaissance Laboratory also received two former ARL contracts. One was the $1.00-per-year contract with the Smithsonian Astrophysical Observatory, which had been initiated as part of the International Geophysical Year program and for which Sergeant Tyson continued to serve as Air Force coordinator. This contract now came under Project 6283, Photo Instrumentation Equipment, Task 62807, Electro-Optical Techniques for Optical Surveillance. Mr. Virgil K. Yenner, also of the Aerial Reconnaissance Laboratory, was assigned responsibility for a contract with the Yerkes Observatory of the University of Chicago whose objective was to determine the possibility of obtaining reconnaissance and astronomical photographs by electronic means at vastly increased speeds. This contract, initiated in June 1958 in support of the Cat Eye effort, was assigned to Project 6239, In-Flight Reconnaissance Data Reduction Techniques, Task 62806, In-Flight Sensor Integration and Data Filtering.[21]

Because of the persistent shortage of manpower, Gebel never could devote sufficient time to the final preparation for publication of the technical papers which he had been writing during the past years on different aspects of Cat Eye research. Nevertheless, he believed that the Air Force should receive full value, in the form of published information, for its expenditure on this work; and he therefore sought now to make up for this deficiency. In the 18 months following the transfer, numerous important technical reports were completed for publication. Both before and after the transfer, furthermore, Gebel made himself available to personnel of ETL and of the Aerial Reconnaissance Laboratory at any time for background information and offered advice as necessary on the maintenance of his former contracts.[22]

The termination of Task 70827, Light Amplification, and the transfer of task activities to other laboratories did not quite put an end to ARL's Project 7072, Research on the Quantum Nature of Light, of which Task 70827 had formed part. There remained Task 70844, Optical Transducing Processes, which consisted mainly of contractual work and had been created to explore certain new principles and techniques that were related or possibly supplementary to the main Cat Eye research effort. However, this task, too, was terminated during the second quarter of FY 1961. The reasons given for termination were "the lack of an in-house effort in the area [since the termination of Task 70827 a year before], the progression into applied research, and the greater need for resources in other more basic areas." The statement of termination issued for Task 70844, like that for Task 70827, indicated that some further basic research was necessary if a development program growing out of the task was to be fully effective; but the planned work of the task was stated to be 95 percent complete. All contractual efforts outstanding under Task 70844 had been completed, and the necessary close-out actions had been initiated. Altogether, Task 70844 expended an estimated 18.8 man years and $365,605 before termination. A total of $255,000 in FY 1961 funds remained on hand and was reprogrammed to other research projects at ARL.[23]

The accomplishments of the Cat Eye project represented a tremendous achievement for a small in-house and contractual research effort -- which constantly suffered from lack of adequate manpower and funding. Whereas other scientists had been able to amplify low light levels with only a modest gain, Gebel had succeeded in doing so by over 20 billion times and had also devised very effective means for enhancing contrast, one of the most essential requirements for military and astronomical applications. By his own research with the help of an average of fewer than three laboratory assistants, and by the initiating and monitoring of carefully screened contracts, he was able to achieve a goal beyond that attained by some of the largest industries in the country.

Gebel claimed as many as 13 patents in connection with his work in light amplification. These were for his contribution of the basic concept of a sequential light-amplifier system and for specific inventions made in the course of his in-house research; the separate patent rights of research contractors for their own contributions were carefully safeguarded. In addition, Gebel received the WADC Outstanding Inventor Award in three consecutive years -- 1958, 1959, and 1960. In 1958 he received a special letter of commendation signed by General Thomas D. White, Chief of Staff, United States Air Force. And as a fitting culmination, in recognition of his exceptional service to the Air Force and to the national defense, Gebel was given the Air Force's highly coveted Exceptional [Civilian] Service Award in the latter part of 1959. The Honorable Dudley C. Sharp, Secretary of the Air Force, made this award (which included both a decoration and a $5,000 honorarium) with the following official citation:

> In recognition of his exceptional accomplishments in the field of electronic optics while serving as Physicist, Aeronautical Research Laboratory, Wright Air Development Center, for an extended period which ended in September 1959. His outstanding contributions to the art of optical amplification have enhanced the defense capabilities of the United States and have created major potentialities for the advancement of astronomy, astronautics, physics and medical science, reflecting highest credit upon himself and the United States Air Force.[24]

Appendix A

TECHNICAL ASPECTS AND MECHANISM OF PERFORMANCE

The act of seeing -- or of measuring light or recording it on photographic film -- consists essentially in counting a portion of the quanta of light emitted (photons) per unit of time from each element of area observed in the field of view. The number of quanta received by an eye or a camera from each element of area is a function of the diameter of the optical system used. Of the photons received, only a fraction is actually absorbed by the rods or cones of the human eye or by a photocathode or photographic emulsion. Only the absorbed portion can be converted into a signal or measured or recorded by any instrument or film. The ratio of resulting events, electrons, or photographic grains to the number of photons received is called the quantum efficiency.

Attempts at light amplification by different workers as early as the 1930s employed the techniques used in image converter tubes. Some of these used single stages and some used several stages cascaded. In such systems, the image is focused onto a photocathode, each small area of which emits electrons in a number substantially proportional to the amount of light striking it (usually on the order of one electron for each 10 to 20 photons). The energy for the intensification is gained by accelerating these electrons in an electrostatic field, and image formation is maintained by an electronic lens.

In the simplest tube arrangement of this system, the electrons strike the reproducing phosphor screen directly. The electron absorption and resultant excitation of the phosphor may produce an emission in recent tubes of more than 500 photons for each electron absorbed; the number depends on the accelerating potential applied, which may be 10,000 to 30,000 volts. The image may then be photographed.

However, the total gain achieved by such systems is relatively low, and the light levels produced still require very good adaptation of the human eye. If, for example, the lowest level of illumination during the darkest portion of the night is 3×10^{-5} foot-candle, and if we assume 10 percent reflection and an amplification factor of 10,000, the final reproduction would have a brightness of only 3×10^{-2} foot-candle, and if we assume 10 percent reflection and an amplification factor of 10,000, the final reproduction would have a brightness of only 3×10^{-2} foot-lambert. This is only the brightness of white paper in moonlight. Such a device is entirely unsatisfactory on a vessel or on an airplane, where the observer might be located in a brightly illuminated room looking at a very poorly illuminated scene or landscape. Also, this type of intensifier usually permits only one person to look at the scene at a time.

A light-amplifying device for achieving optimum intensification should have enough amplification to transform the lowest light level to be viewed to a level that will permit the presentation to be made in full daylight surroundings. Only the sequential light-amplifier system as explored in the Cat Eye project has the capability to produce such very high amplification and the possibility of simultaneous viewing by a number of observers. A system such as this can also be used for remote observation, which may be a very important factor for military application since in many cases observation will be required where it is impractical to place a human observer.

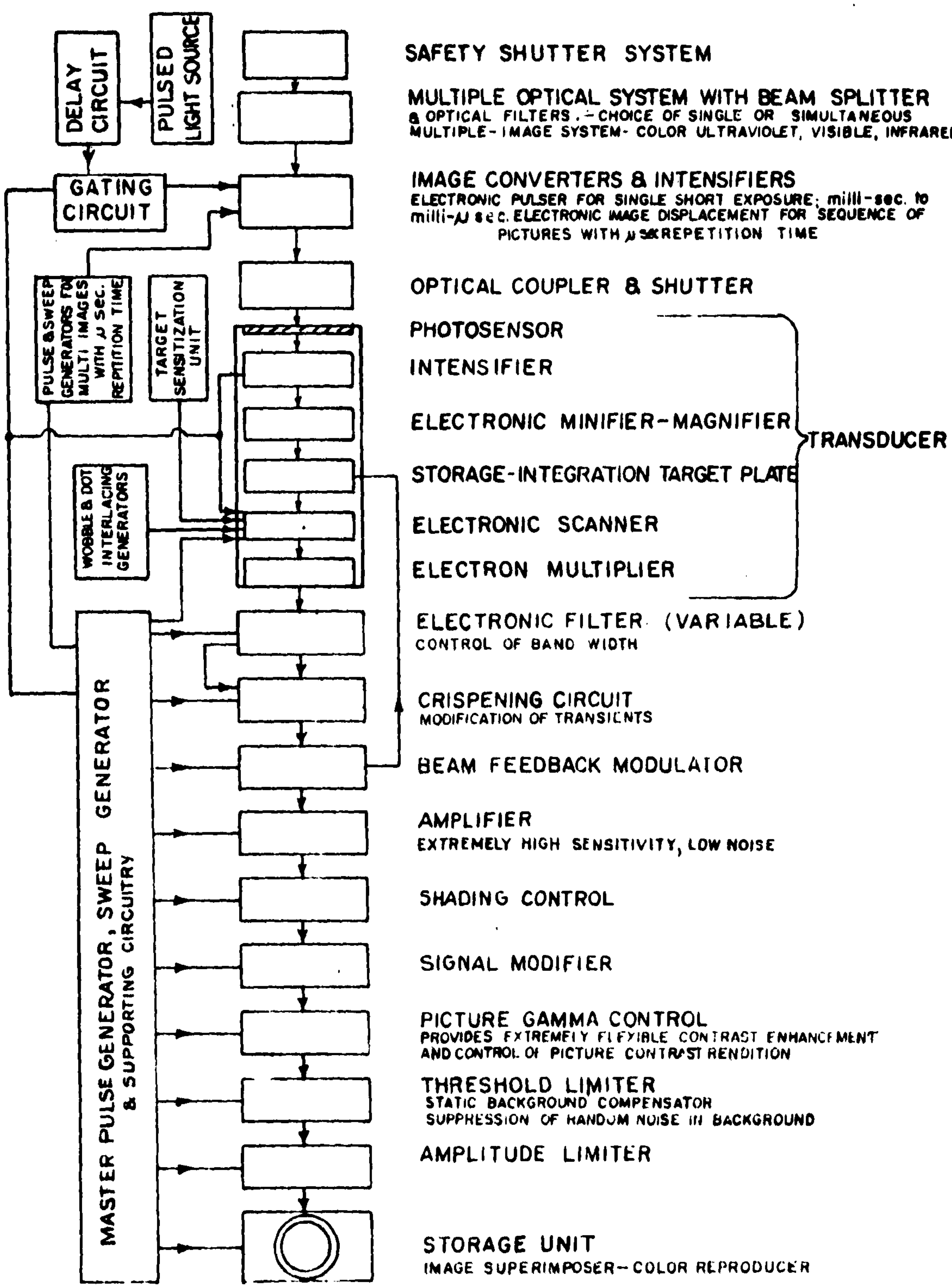
Since detection of light is a counting of quanta, light amplification is faced with certain limitations determined by the laws of statistics. Let us assume that we are viewing a uniformly illuminated area which reflects light homogeneously in all directions and that this area is divided into small sections of equal size; we will then find that we do not have exactly the same number of photons coming from each section. The possible deviations among the number of photons from the different sections may be calculated by the classical Poisson formula. It will be recognized that the percent deviation becomes greater as the number of photons received becomes less. Thus, for very low light levels, the

Sequential Light-Amplifier System

The sequential light-amplifier system can be operated with several different types of front-end arrangements. With the most simple arrangement, a low-light-level scene in the visible portion of the spectrum is detected and reproduced in black and white. A more advanced system will detect image information from the ultraviolet to the far infrared and after intensification will reproduce the information in different colors; furthermore, the visible information from the scene can be split into the predominant colors for easier identification.

The image converters between the multiple optical system and the storage transducer may also act as preamplifiers and as electronic shutters. (These image converters can stop very fast motion, making possible very short exposure times in the milli-micro second range.) The most efficient optical coupling between image converters and the photosensor of the transducer is by fiber optics. The transducer intensifier then assures a sufficient intensity of the electron image to provide a usable signal-to-noise ratio in order to overcome the scanning beam noise. The electronic minifier-magnifier matches the initial resolution of the device to the effective resolution determined by quantum mechanical considerations for obtaining optimum results. The type of scanning system can be either orthicon, ebicon or isocon mode, but it has been found that the isocon mode results in the most effective system. The storage target assembly and scanning system can be constructed in such a manner that a signal will only be reproduced from moving targets in the field of view, and several usable systems of this type have been demonstrated.

The electron multiplier assures that the signal will be sufficiently stronger than the input noise of the following amplifier stages. The electronic filter matches the bandwidth to optimum signal-to-noise condition. The crispening circuit makes the edges sharper for better definition. The beam feedback modulator increases the dynamic light range of the system so that strongly charged target-plate areas are sufficiently neutralized without losing weak information in the dark areas. The shading controls permit cancellation of background shading introduced by the sky background, the photosensor, the scanning system or other factors. The signal modifier permits differentiation and rectification of large areas in order to reproduce the edges only. This can make fast visual recognition possible in pictures where details contained in a larger area have to be detected. The picture gamma control permits increase of the contrast to any useful value; furthermore, the gray-scale characteristics can be altered with this circuit. The threshold limiter permits suppression of signals below an arbitrarily determined intensity and therefore provides static suppression of the background and inherent noise. The amplitude limiter permits not only clipping of the signals caused by bright objects but also clipping of the noise riding on top of the information signal, which may occur at low light levels. The storage unit can reproduce continuously up to 100 frames per second and may also store and display any selected frame for several minutes or integrate a large number of frames. (Slide-like performance at frame rates of one per several seconds is possible.)



BLOCK DIAGRAM OF SEQUENTIAL LIGHTAMPLIFIER SYSTEM.

deviations which may occur will be so great that small differences in the brightness of the different areas that would be easily seen at high light levels can no longer be detected. To overcome this difficulty, we either increase the size of the individual areas or count for a longer time; that is, we decrease the resolution or lengthen the exposure.

Another limitation in light amplification is the dark current produced by any electrical transducer -- that is, the current in the absence of any light. If the dark current would be absolutely equal from one area to the next, it would not matter. However, we may expect the same deviations here as are expressed by the Poisson formula; therefore, to reproduce a useful intensified picture, the effects of the light focused on the transducer must be larger than or, preferably, greatly exceed that deviation.

The main sources of the dark current are: thermionic emission by the photocathode; emission produced by the bombardment of the photocathode by positive ions; field emission; emission by phosphorescence; and feedback of stray light. To reach the maximum sensitivity it becomes mandatory to keep the dark current as low as possible, which can be done by cooling of the photosensor.

The sequential light-amplifier system consists of an optical unit, pick-up unit, electronic amplifier-modifier unit, storage reproducer unit, auxiliary circuits, and associated power supplies. The optical system images the scene information onto the photocathode of the transducer of the pick-up unit, and the optical image is then converted into an electron image. After acceleration and intensification, the electrons produce an electrically positive charge image on a storage target plate. The scanning beam scans this charge image and converts it into a time-sequential video-type electrical signal. This signal is modified by a threshold-limiting circuit and an amplitude-limiting circuit, filtered to remove certain unwanted signals, fed to the electronic amplifier-modifier, and, finally, used for modulation of the electron beam of a cathode ray tube in the storage reproducer unit. An electron beam scans the phosphor of this cathode ray tube in synchronization with the scanning beam in the pick-up transducer. The intensified image that is

reproduced on the phosphor screen of the cathode ray tube may then be visually observed or photographed by an ordinary still or motion picture camera.

With a conventional transducer, the noise in the scanning beam limits the low-light-level performance. This limitation is overcome in the sequential light-amplifier system by placing one or more light-intensifier stages between the target plate and the photocathode of the transducer.

Two principal means for accomplishing amplification were considered and investigated in the course of the Cat Eye research effort. The first of these is a "sandwich-type" intensifier, consisting of a fluorescent screen and an essentially contiguous photocathode, which provides a multiplication of the electron flux of the electron image of better than thirty. The energy for the multiplication mechanism is gained by accelerating the electrons of the electron image with 10,000 to 20,000 volts per stage, whereby each electron absorbed in the fluorescent screen produces several hundred photons of light. About an average of 15 of these photons will cause the emission of one photoelectron from the contiguous photocathode. A second class of intensifier -- known as the transmission-secondary-emission type -- is a thin-film structure consisting of a material which is capable of producing secondary emission and is coated on the primary side with gold or another suitable material. This type was developed by Westinghouse Electric Corporation, operates at about 4,000 volts per stage, and provides a higher resolution than the first type, but has a lower multiplication factor (about four). The primary electrons striking the film on the one side cause the direct emission of a larger number of secondary electrons on the other side. The transducer with the highest sensitivity was achieved under contract with the RCA Laboratories at Princeton, N. J., where Dr. George Morton headed the work, and used a three-stage sandwich-type intensifier.

The low-light-level performance of a two- or three-stage sandwich intensifier transducer is limited almost only by the fluctuations of the dark current of the first photocathode of the intensifier arrange-

ment, since the intensification is adequate to overcome the noise of the scanning beam. At light levels where these fluctuations become visible, the resolution is determined by the quantum nature of light -- that is, during the scan time the smallest resolvable areas of the photocathode collect such a small average number of quanta that the statistical variations of these quanta determine the effective resolution. At light levels where the number of quanta available is adequate, well-built systems are able at present to achieve approximately 800 television lines per image without intensifiers and 350 lines with a double-stage intensifier; however, since the optical image may be magnified before it reaches the photosensor of the transducer, this low resolution is not too important.

It is extremely difficult by any other arrangement to equal the gain in light intensification that is possible with this type of equipment. Experimental systems have been built by the Aeronautical Research Laboratory (ARL) providing useful intensification from a scene brightness of 5×10^{-9} foot-lambert to a brightness of 100 foot-lamberts on the reproducer screen, which is a useful gain of twenty billion; but even higher gains are now possible (1,000 billion). Under threshold conditions these experimental systems had a resolution as determined by quantum mechanics. Such gains cannot be achieved with conventional cascaded image converter tubes, and the sequential light-amplifier system offers still further advantages: contrast enhancement and control, possible transmission of the signal by wire or broadcast, simultaneous reproduction on any number of cathode ray tubes, and direct large-screen display of even the faintest detectable object in daytime light surroundings.

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In all the foregoing discussion, one important problem was expressly left out as requiring separate treatment. This is the choice between different methods of scanning and of signal generation in the scanning sections of light-amplification transducers. The two most important modes are the orthicon and the isocon scan. In the orthicon mode, for dark portions of the image, essentially all the electrons in the scanning

beam become the return-beam electrons and are focused onto an electron multiplier from which an amplified video signal is obtained. For brighter portions of the image, some of these scanning-beam electrons are needed for neutralizing the target plate, and the number constituting the return beam and reaching the multiplier is reduced. In the isocon mode, the return beam is produced by electrons scattered from the target plate; for dark portions of the image, little scattering occurs, but it increases as the brightness increases. The important thing to observe here is that for the darkest portions of the scene, where the highest sensitivity is essential, the total return-beam current and therefore also the electronic noise contained in it are at a minimum. This results in a high signal-to-noise ratio. For this reason the isocon scan is more suitable for highly sensitive optical amplifying systems than the orthicon scan in which the return beam, and therefore the electronic noise, are greatest for weak signals.

Also, the isocon mode has a wider dynamic range (i.e., a larger ratio between the maximum acceptable light signal and the minimum detectable) without resetting the beam controls. The deficiency of the orthicon mode in this respect can be explained as follows: if detection of information from the dark portions of the picture is desired, the smallest possible value must be chosen for the scanning beam which is sufficient to neutralize the target plate in that section, in order that the noise in the return beam may be kept small enough to permit detection of the signal. However, such a small value for the scanning beam is insufficient for neutralizing the charge on the target plate corresponding to higher light intensities. This results in an increase in the size of the reproduced image of the object and may cause the images of high-intensity point sources to cover a large portion of the reproducing screen.

The isocon scanning technique has been known since 1949, when it was conceived by Dr. Paul K. Weimer of the RCA Laboratories in Princeton, who built and demonstrated the first isocon tube. However, no further use was made of it until Gebel considered it for use in light-intensifier systems, especially in space vehicles and other applications where the

manual adjustment required by all orthicon tubes thus far built is very difficult. Contracts to investigate the isocon mode were initiated by ARL with Dr. Weimer as part of the Cat Eye project. These resulted in transducers which considerably outperformed those using the orthicon mode and required less preamplification.

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Another special problem -- or, rather, special advantage of the sequential light-amplifier system -- is background suppression. This cannot be achieved with conventional image-converter-tube intensifier arrangements, but with the system conceived by Gebel at ARL it becomes feasible to suppress not only the background but also unwanted details in the picture itself. Two main approaches to background suppression were explored in the ARL in-house and contractual research effort. The most simple device, the static background suppressor, is capable of suppressing the signal caused by a homogeneously luminescent background containing a shading gradient and signals of detailed structures, if their signal level is weaker than that of the target. The latter objective is achieved by means of electronic threshold-amplitude limiter circuits in the video amplifier. The second technique has been publicized widely for its ability to reproduce moving objects and exclude nonmoving objects. It employs a dynamic background compensator which works regardless of the level of luminescence of the scene, and which produces a video signal from the moving object even when the static background suppressor may fail because of stronger pulses in the video signal being emitted from a secondary stationary object. One benefit of the dynamic background compensator is to eliminate the requirement for a highly skilled operator to differentiate the background clouds from the primary object. Further, when triggering automatic circuits with conventional arrangements, the target signal must be considerably stronger than the background; but in a sequential light-amplifier system with dynamic background compensator the automatic modification of the video signal for improved discrimination corrects this need for a stronger signal from the target and also provides for better detection of moving objects in the near infrared.

Gebel at ARL and Dr. Morton of RCA conceived several different methods of creating a dynamic background compensator, and workable experimental systems were produced. Gebel obtained a patent (number 2969477) on one method which featured a field-sequential-operated transducer similar to an image orthicon, to be used as the pick-up tube. Whereas the conventional image orthicon target plate secondary-emission yield for the primary photoelectrons with commonly used accelerating voltages is always larger than one, this special transducer has a secondary emission yield of electrons impinging on the target plate which can be made arbitrarily larger or smaller than one, dependent on the accelerating voltage between the photocathode and target plate. The tube is field-sequential-operated so that alternately an image pattern with either a positive charge or a negative charge is produced on the storage target plate. Positive charges are produced by a secondary yield larger than one, resulting in electrons removed; negative charges, conversely, are produced by a secondary yield smaller than one, resulting in the depositing of electrons. If nearly equal pictures are sequentially exposed to the transducer photocathode, and by arbitrary choice of exposure time for the alternate fields or by operating additional field-sequential apertures the number of charges of the positive and negative charge patterns is made equal, then all the identical details in the image will cancel, and only the disparate portion of the charge image will remain after the compensating second field exposure. Before this mode of operation is repeated, the information is taken off by a scanning beam and can be amplified in the usual method for use on a visual presentation unit. If it is necessary to achieve the highest possible sensitivity, intensifier stages must be used before the storage target plate. The read-out is performed in this system by forming the video signal from the remaining charge that is left at the target plate after the second electron image has neutralised the charge pattern caused by the first image. In conventionally operated image orthicons only positive-charge images occur on the target plate, and therefore the read-out may be achieved with a low-velocity scanning beam; but in this system, which employs differential imaging, the remaining information after

the compensating second exposure may be either a positive or negative charge. Therefore, since low-velocity scanning beams remove positive charges only, a high-velocity beam must be used.

One of Morton's solutions to this same problem was to use a low-conductive and high-capacitive mica target plate. In this method, only changes in the viewed scene are transferred from the side which is hit by the electron image to the side which is scanned, resulting in an output signal of the transducer representing the moving object only. A system built on this principle was effectively demonstrated in a parking lot at ARL. The parked cars could not be seen, but people walking through the lot were visible for a time and then disappeared from sight; next one could see a car door open and close, after which an automobile appeared suddenly as it started to drive away.

Technical Military Applications

Throughout the brief span of aviation history there has been a definite requirement to see objects that the human eye at its best could not distinguish. Many situations require extraordinary vision, sufficiently adapted to darkness for perceiving low-light-level objects in the performance of a military mission. But even pilots with very good eyesight may differ in their visual threshold from day to day. Observations by the human eye under threshold conditions are never very reliable, because the variable factors of imagination and fatigue as well as other psychological factors may influence the view obtained. For example, when an observer has to view alternately cabin instruments having a relatively high brightness and ground objects having low light levels, valuable time is constantly lost because of the lapse required for readaptation. During this adaptation time the observer can view neither the ground nor his instruments with full reliability. If the cabin light level were lowered to the level of ground light levels as a corrective measure, it would be nearly impossible for the observer to view his instruments quickly and reliably. The sequential light-amplifier system offers a solution, because the low-light-level objects on the ground can be reproduced with a brightness that is practical for the interior of the cabin, approximately 20 to 50 foot-lamberts.

It has been found that the time required for mental comprehension of an event seen is a function of the contrast of the scene. This light-amplifier system, since it also provides the means to increase the contrast by a very large amount, makes possible a faster reaction by the observer.

To see the reason for the time lapse in viewing objects at very low light levels with the unaided eye, it might be well to understand the workings of the human eye in a situation of this nature. Obviously, the optic nerve can only be excited after some minimum chemical change in the visual purple fluid of the retina sensors, which is required for visual sensation, has occurred. At threshold light levels we must assume for the eye an integration time of approximately one second to fulfill quantum mechanical considerations, while at a high brightness level this may be reduced to approximately 0.1 second. Thus, details on a brighter scene may be distinguished more easily and quickly than the same details in an actual night scene, if the observer is able to view the latter at all. When this time lapse is considered in terms of an aircraft moving at a speed in excess of mach two, the tenth of a second gained or lost can play a vital role. It should also be noted that night vision is very poor in the fovea, the center of the retina, which is made up of cones less sensitive than the rods covering the outer areas of the retina. However, most daylight information is focused and perceived at the fovea, so that the observer may instinctively focus information there. Thus one potentially valuable function of a light amplifier is simply to bring the light level to a point where it can be satisfactorily used by the _fovea centralis_.

In addition, a well-designed light amplifier can provide a colored picture, which will be helpful for faster perception and also for better detection of camouflage. The choice between a two- or three-color system received careful investigation in the in-house phase of the Cat Eye project. While a three-color system might be preferable for commercial entertainment, a two-color system would probably be sufficient for military purposes and would lend itself both to a simpler arrangement and, in some cases at least, to a higher sensitivity; and it would still have a detec-

tion advantage over black-and-white light amplification. Several promising approaches to nonmechanical military two- or three-color systems were conceived. For one method, which used electroluminescence, a patent (number 3005108, Solid State Light Amplifier for Color) has been granted to the United States Government with Gebel as the inventor.

Among the specific operational missions in which light amplification can play a useful military role, perhaps the most obvious are night bombing and reconnaissance. However, many others are possible. For example, ARL scientists studied several potential applications in the field of rescue operations both at sea and on land. Such operations would be especially effective if the amplifier system incorporated a multialkali photocathode developed by RCA which is sensitive not only to visible light but also to infrared wave lengths near the visible. Thus, if a survivor were provided with an ordinary flashlight equipped with an infrared-transparent filter, he could transmit a special signal which might be changed from day to day for security purposes and which would not be detected by the unaided human eye. Although enemy observers would be unable to locate the survivor, friendly rescue aircraft could easily do so, using the image on the light-amplifier display tube to guide their course. Indeed, a high-performance amplifier system would be well suited for rescue operations even without the use of an infrared signaling device. With its low-light-level imaging ability, it could detect an object or survivor even on a very hazy and moonless night, provided at least some small amount of light were reflected.

The advantage of a passive operation, where no indication is given of the presence of the mission, is of course extremely important for many different applications. Activities requiring stealth, such as night parachute missions and night landings in unfamiliar terrain, can achieve a considerable increase in the degree of safety by making use of light amplification.

Likewise the extremely high sensitivity that is attainable with the sequential light-amplifier system makes possible a new passive means for detecting and tracking an oncoming intercontinental ballistic missile or satellite. In this connection it is important to note that the usual

radar tracking bases reveal their presence to an enemy and even provide a convenient homing base for a missile designed for their destruction. By comparison, any number of optical amplifiers can be placed in advanced locations or carried aloft, and the destruction of all these sensors by a potential enemy would be practically impossible. Especially promising for this type of military work are the moving-target transducers, which enable an amplifier chain to produce an image of moving objects only and which can be used for electronic range finding.

In addition to the requirement for aiding the human eye, in the military field, there exists the necessity for aiding present photographic systems, especially in situations where not only the intensification of light is essential but also an increase in contrast between the objects in the field of view as they are presented in the intensified image to the photographic recording device. The sequential light-amplifier system fulfills these requirements, and in fact can increase the contrast of the reproduced picture on a cathode-ray tube screen arbitrarily to any practical useful value. Its high capability to detect and enhance small differences in contrast has been amply demonstrated in the effective daytime tracking and photographic recording of artificial satelites, etc., which would not be possible in most cases by any other system.

Astronomical Applications

Astronomical use has proved to be one of the most effective ways of operationally testing the sequential light-amplifier system. The initial astronomical experiments were accomplished through long and friendly cooperation with the Weaver Observatory of Wittenberg University. The arduous assembling and testing of equipment by Gebel and his team, with Professor Lloyd Wylie of Wittenberg as consulting astronomer, enabled ARL to prove the capabilities of the system in the field of astronomy and led to further intensive testing by the Smithsonian Astrophysical Observatory.

As in the military applications, there also exist many situations in astronomy where the intensification of light is not as essential as a large increase in contrast between objects in the field of view. The

basic system tested at Wittenberg was uniquely capable of fulfilling both requirements, and it therefore made possible the reproduction on the cathode-ray tube screen of celestial bodies during daytime hours without reproduction of the brightness of the daytime sky.

The extremely high sensitivity of the sequential light-amplifier system, together with its capability for contrast enhancement, offers a means to probe farther into the universe than has been possible with standard optical telescopes. The theoretical figure of merit for the system is thirty-fourth apparent magnitude -- about 10 magnitudes fainter than any star yet recorded. The system likewise has the potential to increase the productivity of astronomical telescopes by permitting the use of exposures hundreds of times shorter than previously possible, and to allow smaller telescopes to accomplish tasks that otherwise could only be accomplished with the very few large telescopes available. It is potentially adaptable to astronomical use with a balloon or satellite vehicle as well as in a ground observatory. Indeed, a single amplifier with different lenses, if taken to sufficient altitude, could transmit simultaneous infrared, visible-light, and ultraviolet images.

In many cases it is desirable to make the focal length of an astronomical telescope adjustable for optimum performance. The resolving power of the telescope should be properly matched to the resolving power of the photosensor (human eye, photographic plate, or photocathode). If the resolving power of a telescope is considerably less than that of the light detector, the quanta of light collected by the telescope are distributed over an unnecessarily large surface of the light-detecting element. This results in lower sensitivity, which can be solved by proper matching and reducing of the image size. Conversely, if the resolving power of the telescope is higher than that of the sensor, the individual resolution components of the sensor will not show the actual and optically distinct scene elements projected onto them but will show only average illumination. The resulting loss of detail would impair the capability of a sequential light-amplifier to detect low-magnitude stars against a background of radiant sky; but the difficulty can be avoided

by increasing the size of the telescopic image. Considerable work was done by Gebel and his team along these lines with the Wittemberg telescope. The original four-meter focal length of the telescope was made changeable from 0.5 meter to 40 meters, but most pictures were taken with 15-meter effective focal length.

Sometimes astronomers use an image converter tube as a light intensifier between the telescope and photographic emulsion. However, no increase in contrast is possible with such an arrangement, and the larest amount of light from the reproducing phosphor screen of the image converter tube which can be collected and transferred to the photographic plate with conventional optics is only about ten percent. Special optical couplers will permit a transfer of as much as 30 percent, but their cost is in the order of $5,000 to $10,000. Further, if several image converter stages are cascaded for greater sensitivity, resolution is impaired; and if gains of several billion times are sought (such as can be obtained with the sequential light-amplifier system) the result would be a nearly complete loss of image information in the final reproduction.

<u>Other Applications</u>

Light amplification by the techniques explored in the Cat Eye project offers not only the Air Force and other government agencies but also science in general numerous instrument capabilities which heretofore were not considered feasible.

Some of the most important applications, potentially, are to be found in the field of medicine. At present, when a doctor is making an x-ray examination of a patient by means of a fluorescent screen and needs to see the fine detail of the image, he must either spend considerable time adapting his eyes to darkness or use an unnecessarily high x-ray intensity, so that, if repeated observations are needed, the exposure may be dangerous to the patient. Also the doctor himself is in considerable danger from stray x-rays if he examines a large number of patients daily. In practice, therefore, x-ray photographs are preferred to instantaneous observation with a fluoroscope. Yet in certain cases, as in observing a pulsating heart, information can be obtained from a fluoroscope, that cannot be revealed by still photographs. And if the doctor

looks at the screen with a sequential light-amplifier unit, not only can he reduce the x-ray dosage to a level less harmful for the patient, but also he himself can sit in another room in safety while observing the image at daylight brightness. At the same time, with an amplifier of this type he can increase the contrast in the image and thus see details he otherwise would miss.

Use of the sequential light-amplification techniques in this and other medical situations has been held back by the high cost and relatively short life of presently available equipment. But experimental use has already occurred. In fact as early as 1954 a fairly primitive amplification system built on such principles was installed in a Westinghouse mobile x-ray unit at Wright-Patterson Air Force Base. Thanks to the contrast enhancement possible with this system, the commercial x-ray unit yielded an amount of detailed information that could not have been obtained otherwise. In still other tests, motion pictures have been made from the reproducer screen of a sequential light-amplifier system showing the pulsations of blood in the kidney of a live rabbit.

Additional research applications exist in the field of nuclear science. Dr. George T. Reynolds of Princeton University, with a light-amplification transducer produced under contract by RCA and loaned to Reynolds by ARL for research use, has already recorded tracks of a previously undetected nuclear particle. Then, too, systems such as this hold obvious promise for obtaining new data on the essential nature of light itself.

Even more obvious are the possibilities in commercial aviation, where light-amplification might well prevent major disasters. For example, by this means the landing strip may be shown more precisely to the pilot, when lighting conditions are inadequate or unfavorable. A considerable number of major accidents occur because the pilot sets the plane down too soon -- as in two very similar accidents that occurred at Casablanca, Morocco, with both planes (one French and one Czechoslovakian) exploding because their pilots set them down before reaching the runway. These disasters probably would not have happened if an optical-amplifier view had been available to the pilots.

Appendix B

TECHNICAL PUBLICATIONS ISSUED IN CONNECTION WITH THE CAT EYE RESEARCH EFFORT

(Note: These reports are available to qualified requestors from the Armed Services Technical Information Agency and, except for one classified report, to the general public from the Office of Technical Services, Department of Commerce.)

WADC TN 54-5 (ARL 13)

R.K.H. Gebel, A Portable Low-Level Lightmeter. 3 p.; 1954, reissued April 1961.

Explained herein is the operation and calibration of a portable low-level lightmeter designed in connection with work on the problem of light amplification. This light meter can be used to determine the light levels from as low as 10^{-8} foot-lambert.

WADC TN 54-5 (Sup I)

R.K.H. Gebel, A Portable Low-Level Lightmeter, Supplement I: Low-Level Lightmeter for the Near Infrared. 6 p., March 1955.

Results of former attempts to establish a value for visible radiation in the region between 7000 and 11,000 A in the near infrared of the night sky have been unreliable due to lack of precision instruments. In this modification for the low-level lightmeter, an infrared image-converter tube for converting the infrared into visible radiation has been employed. Further, better stabilization in the transformer and change of voltage in the photomultiplier are made to achieve a higher sensitivity of the meter. Calibrations were made similarly to the method explained in "Portable Low-Level Lightmeter." Improvement in registering the brightness of the night sky in the near infrared (6300 to 11,000 A) was noted in the test made on the night of 8 March 1955.

WADC TN 54-5 (Sup II)

R.K.H. Gebel, A Portable Low-Level Lightmeter, Supplement II: Modified Low-Level Lightmeter for the Near Infrared. 5 p., March 1955.

Experiments to achieve a higher sensitivity in the low-level lightmeter for operation with a narrow bandwidth monochromator in near infrared observations have been advanced by an experimental photomultiplier tube made by the Dumont Tube Corporation. This tube produces a sensitivity approximately 5 times greater than was possible with previous lightmeters. Recommendations are made for further increasing effectiveness in use of the low-level

lightmeter by incorporating a new Farnsworth 16-stage near infrared photomultiplier tube, 16PM1, with a very large aperture and short-focal-length lens.

WADC TN 54-5 (Sup III) — Myron H. Yang, A Portable Low-Level Lightmeter, Supplement III: Transistorized DC to DC Power Converter. 6 p.; August 1959.

A modification for the power supply unit for the low-level light meter, Technical Note WADC 54-5, was made by replacing the conventional relay-type vibrator with power transistors. Advantages in power consumption and reliability of this modification are discussed.

WADC TR 55-155 (ARL 175) — W.O. Reed, High Speed Shutter System.

A high speed camera system capable of recording 16 pictures, each exposed to the light from the object being viewed for 3×10^{-7} to 3×10^{-6} seconds, was developed during the contract period. The system is capable of doing this with an overall light gain so that considerably less light need illuminate the object under study than is required by high speed camera systems based on other physical laws. The experimental evidence furnished shows that photographic negatives having densities of 0.5 can be achieved with 1 microsecond exposure and 200 foot-candles illumination incident on the photocathode (150 watt projection lamp at 110 V) with readily available photographic film and camera optics.

The essential shutter element in the camera system is an image converter tube which can amplify the light by factors of over 25. The photoelectrons emitted by the light from the object under study are controlled in their accelerated flight to the fluorescent screen by a mesh grid. The grid receives positive voltage pulses of 65 volts amplitude from the circuitry developed for the purpose. These pulses are synchronized with the phenomenon being observed and are controllable in width and spacing by the circuitry. The use of 20 KV final anode potential ensures high efficiency in the conversion of electron energy into luminous energy from the fluorescent screen. The 16 separated pictures are obtained by synchronizing the deflection currents through the yoke with the grid shutter pulses such that while the shutter is open the sweep is held steady on the screen, and when the shutter is closed (grid negative), the current through the yoke changes by the right amount to have the picture in a new position when the grid again becomes positive. A certain amount of jitter caused by intercoupling of the circuits and by response time of the deflection yoke limits the resolution of the dynamic picture to 16 lines per mm.

The circuitry provides for the following adjustments: 16 successive pictures can be spaced 2, 5, or 10 microseconds apart.

The shutter pulse unblanks the photocathode of the shutter tube for each picture with a rise time of approximately 0.05 microseconds and with variable delay of 1-3 microseconds. Synchronization of the scan is obtained from either single or continuous triggers. An adjustable delay between the input trigger and the first picture is also available.

Auxiliary equipment includes a magnetic blanking yoke, associated circuitry and a synchronized pulser for operating a photoflash lamp.

WADC TN 57-318 R.K.H. Gebel, Light Amplification and its Importance in Modern Warfare. 7 p., September 1957. ASTIA AD 131047.

The technical possibilities and the scientific limitations of light amplification are outlined. Its importance in military operations is discussed, with reference to the physiological and psychological reactions of the observer, as well as the physical factors. The possible technical approaches to light amplification are explained in the historical sequence of the research applied to them; and probable future developments are discussed.

WADC TN 58-110 R.K.H. Gebel, Electronic Contrast Selector and Grain Spacing to Light Intensity Translator for Photographic Enlargements. April 1958. ASTIA AD 151178.

An electronic method is described which can readily extract information from a very low contrast photograph, which is almost impossible to detect with the human eye. The electronic equipment, which can be called a computer, counts developed grains in the photograph and presents a revised photograph on a cathode ray tube in which concentrations of grains that are in excess of the background over an area large enough to be significant are printed in gray scale values. The cathode ray tube picture is photographed for record. This device can be used for obtaining information from photographs of the earth taken from a space vehicle or from the moon, or for obtaining photographic records of celestial bodies that are normally lost in the background of the universe.

WADC TN 58-114 R.K.H. Gebel, A Military Color Television System. April 1958. ASTIA AD 151198.

The need for a good practical military color television system is emphasized and discussed. The technical possibilities and limitations of color television systems, in general, are discussed. The more important types of color systems are outlined, with emphasis on motion-detection limitation. A superior color television system for

general military application is outlined, which is suitable for use with or without optical amplification.

WADC TN 58-116 R.K.H. Gebel, Effects of Bright Point Light Sources on Low Level Image Orthicon Detectors. 5 p., April 1958. ASTIA AD 155503.

For military applications, the image orthicon type tube faces a rather serious target detection problem and limitation, when viewing low light-level target scenes, due to high brightness point light sources that may appear in these scenes. The high brightness point source effect, and the causes thereof, are discussed in detail. Electronic means for compensating for this effect are discussed; appropriate changes in the internal components and geometry of the tube are suggested.

WADC TN 58-117 R.K.H. Gebel, Microphonic Effects in Image Orthicons. 10 p., April 1958.

Image orthicon tubes are often subject to microphonic effects in their outputs due to physical vibration or oscillation of internal tube components such as the target plate, etc. Both experimental and theoretical investigations have been conducted on these tubes in order to determine the cause and best solution to the microphonic problem. While the investigations have shown that it is possible to eliminate microphonics in these tubes electronically, the best solution to the microphonic problem can be obtained by careful design and construction of vibration-proof internal tube components.

WADC TN 58-118 R.K.H. Gebel, An Image Orthicon with a Narrow Range of Electron Energy in the Scanning Beam.

A method of improving the low light level performance of image orthicon devices, by making certain basic design changes in tube geometry, is outlined and discussed. The electron-optical relationships for the scanning beam are developed. In the development, it is shown that, for a scanning beam of narrow electron energy range, the beam modulation factor can be made very low, thereby improving the performance of the tube. It is also shown how a very accurate control over both the energy range and the direction of the electrons in the scanning beam can improve both focus and resolution of the scanned picture.

WADC TN 58-324 R.K.H. Gebel, Daytime Detection of Celestial Bodies Using the Intensifier Image Orthicon. October 1958. ASTIA AD 204793.

This report presents a theoretical analysis dealing with the limiting magnitude of a celestial body, using the intensifier image orthicon. Some photographs are shown illustrating the potentialities for contrast of this instrument. The theoretical calculations deal

first with the fundamental limit set on the detectable magnitude by quantum statistics and then with the limits imposed by characteristics of the intensifier image orthicon in its present state of development. The pictures include daytime photographs of astronomical objects and a full face photograph of the moon showing a large amount of detail that cannot be obtained in such a picture by purely photographic methods.

WADC TR 58-422 S.J. Wooten, A Multi-Frame High Speed Shutter Camera. 44 p., June 1958. ASTIA AD 155848.

The high speed camera was devised to photograph extremely fast moving phenomena at low levels of light, which existing high speed cameras were unable to do. This study covers an ultra high speed diagnostics camera in the form of a "gated" image converter, having a light gain and a resolution satisfactory for diagnostic photographs. The high speed shutter was designed to produce a series of pictures on the phosphor of a pulsed image converter with an effective exposure of less than .01 microsecond.

An image of photons focused upon the photocathode of the image converter produces an electron image which is focused by electrostatic lens rings during the transit time of the photoelectrons. The large cross sectional beam of photoelectrons is deflected by an electromagnetic deflection yoke. The beam is deflected to sixteen different points on the phosphor screen, and as the electrons impinge on the phosphor they liberate photons to create an image. The time interval between photographs is adjustable from two to ten microseconds.

The high speed shutter camera of the Engineering Physics Branch, Aeronautical Research Laboratory, Wright-Patterson Air Force Base is now capable of single shot operation to produce photographs with the effective exposure. This development had made the high speed shutter tube one of the fastest photographic devices in existence.

WADC TN 59-54 R.K.H. Gebel, The Photographic Exposure Time for Astronomical Pictures. January 1959. ASTIA AD 210752.

An analysis is made of the factors affecting the photographic exposure time for celestial objects. The minimum number of quanta that must be received from a star, and the minimum number per unit solid angle that must be received from an extended source, to reach the photographic threshold, are determined, for the case when the camera is carried on an astronomical mount. The treatment is then extended to the case of a satellite, or other rapidly moving object near the earth, when the camera position is fixed with respect to the earth.

WADC TN 59-131 R.K.H. Gebel, The Limitations for Night Time Detection of Celestial Bodies Employing the Image Orthicon and the Intensifier Image Orthicon. 44 p., June 1960.

This paper concludes that it is theoretically possible, by using the intensifier image orthicon, to exceed by ten magnitudes the faintest star ever recorded. Generally, the final limit of detectability of faint stars is determined by the randomness in the radiation of the sky background. Further limitations are imposed by the statistical fluctuations in the conversion of photons into electrons at the photocathode and the statistical fluctuations of the photocathode dark current emission. When using the image orthicon without intensifiers, these fluctuations become small with respect to the scanning beam fluctuations. Part I deals with the conventional image orthicon, with the scanning beam fluctuations usually being the prime factor in limiting detectability. An equation is derived which permits calculation of the apparent star magnitude which can be recorded under the made assumption with the image orthicon without intensifier stages. Part II deals mainly with the intensifier image orthicon. Formulas are derived for the intensifier image orthicon for threshold star magnitude number, as determined by the fluctuations in the emission due to sky radiation and photocathode dark current emission.

WADC TN 59-131 (Sup I) R.K.H. Gebel, Measurement of the Beam Modulation Factor for Image Orthicons. 5 p., October 1960.

In WADC TN 59-131 an arrangement is described for determining the modulation factor for image orthicons being operated at threshold conditions. However, it is also necessary to determine the modulation factor when operating an image orthicon at maximum performance, which occurs at the knee of the characteristic curve. A simple but useful method for determining this modulation factor is explained in this supplement.

WADC TN 59-132 R.K.H. Gebel, The Light Amplifier Kinescope Recorder with a Speed of 10 Million ASA Units for Night Photography. April 1959. ASTIA AD 214762.

A speed in ASA units is calculated for the "CAT EYE" light amplifier. The result of a comparison test between an unmodified Lumicon and a Lumicon modified with a single stage intensifier image orthicon is discussed. The modified Lumicon still produced a 200 line picture where the unmodified Lumicon faded out completely.

WADC TN 59-188 R.K.H. Gebel, Long Focal Length Lenses and the Problem of Resolution. 14 p., March 1960.

A method is presented in this report for modifying the effective focal length of an existing telescope. In most

cases the physical length of the telescope is not increased very much by the modification; however, the effective focal length may be increased many times its original value. For this modification it is possible to use various available lenses or those easily secured from available stockpiles. A theoretical analysis is presented and basic calculations developed which permit achieving proper matching of the resolution of the telescope and the resolution of the sensor by using one or more additional lens systems between the telescope and the sensor. These principles are further illustrated in two accompanying diagrams.

WADC TN 59-189 R.K.H. Gebel, Comments on the Possibility of an Optical Radar System.

The need for optical radar equipment is discussed. The selection of the most suitable receiving system is analyzed and calculations for the requirements concerning the radiating source for such a system are computed. A monitor recording system using xerographic principle and a special recording tube is also described.

WADC TN 59-290 R.K.H. Gebel, Light Amplification and Its Usefulness in Astronomical Observations. 28 p., November 1960.

The first part of this paper investigates some limitations in detecting extragalactic nebulas using conventional photographic emulsions. The second part analyzes the applicability of the present state-of-the-art in light amplification, using the closed circuit television system, for detecting such nebulas. The third part discusses the possible use of the latter system for Mars observations.

WADC TN 59-319 Myron H. Yang, A Haze-Meter. 19 p., February 1960.

The possibility of constructing a haze-meter as a useful indicator to the inexperienced observer for daytime astronomical recordings is investigated. Theories involving Rayleigh Scattering form the basis for investigation of more accurate measurements in sky colour by instrument, and an analysis of the nature of scattering particles and the number of processes taking place in the spectrum of scattered light contribute to more definite determinations of the amount of haze.

An experimental haxe-meter was built by using a dichromatic mirror to split the scattered sunlight. The ratio in intensity of red to blue light which is determined by the haze was detected by special photocells with proper filters in a Wheatstone bridge circuit. After correction of certain calibration difficulties, suitable transistorized amplifiers evolved and were tested for amplification. Schematics showing the wiring, housing, mounting, and details of the dichromatic mirror are included.

Also included are spectral response curves and tabulations for Kodak 1241, RCA 6694A photo-conductive cells and circuit diagrams for the amplifiers.

WADC TN 59-323 R.K.H. Gebel, The Possible Use of the Closed Circuit Television System for Optical Rangefinding.

A new transducer capable of automatic background compensation is suggested, for use in an electronic comparator system employed as a passive optical rangefinding technique. The transducer, which is a vacuum tube similar to the image orthicon, achieves the background compensation by neutralization of opposite charge patterns on a special target plate structure. Some of the theoretical capabilities and sensitivities of such a system are analyzed.

WADC TN 59-390 R.K.H. Gebel and L. Devol, Some Early Trials of Astronomical Photography by Television Methods.

The purpose of this paper is to present some astronomical photographs taken with optical amplifiers of the type described by Morton in another paper presented at this symposium. This kind of amplifier has attained the highest sensitivity to low light levels that we have reached up to the present. Its first use by astronomers is scheduled for the near future.

WADC TN 59-404 (ARL TN 60-189) R.K.H. Gebel, L. Devol, and L.R. Wylie, Astronomical Observations by Means of Highly Sensitive Electronic Light Amplification. 26 p., March 1960.

The advantages of observing and photographing celestial bodies with a light amplifier that employs the closed circuit television principle are explored and treated here. Special pickup tubes were developed to insure optimum performance. The electrical signals from the pickup tube are electronically amplified and modified. The image is reproduced by a cathode ray tube and photographs may be obtained from the screen of this tube.

The electronic amplification of the electrical signal permits light intensification of 10^9 times. The modification of the signal makes almost complete suppression of the background possible. It permits astronomical observations during the day and also at night that are not possible with systems in which the background cannot be suppressed. Photographs of celestial bodies taken at the Weaver Observatory of Wittenberg University are included.

WADC TN 59-405 (ARL 17, ARL 221) R.K.H. Gebel and L. Devol, The Limiting Detectivity of Optical Amplifying Equipment. First issued December 1959.

The limits in the ability to produce photographic

recordings for visual detection of very faint celestial bodies in the presence of the sky background by using conventional photography and by employing optical amplification with contrast enhancement and high capacity storage target plates are investigated and compared in this paper. Equations are appended which show the effects of the different variables involved for three types of imaging systems: the conventional photographic system, the image converter, and the closed-circuit-television type of optical amplifier. In this technical report, the last-named system is found superior to the two other systems.

WADD TR 60-5 E. Heath, Photoemitter Preparation by Empirical and Microbalance Techniques.

A design for a vacuum system to be used with a microbalance in the study of photosurfaces has been successfully evolved and tested. The chief problem of such a system appears to be the large volume. By reducing the volume to a minimum and by suitable baffling and restriction, the effect of the large volume has been minimized. A photosurface of the antimony-cesium type has been successfully formed within this system.

An empirical study of photosurfaces has led to a modified multialkali-type photosurface with a maximum overall sensitivity of 140 microamperes per lumen, a peak response shifted to approximately 6000A, and appreciable response beyond 8000A. A tentative processing schedule for forming this photosurface is given.

WADD TN 60-20 G.A. Morton and J.E. Ruedy, Low Light Level Performance of the Intensifier Orthicon. March 1960.

This discussion of basic principles for development of the intensifier orthicon utilizes television techniques combined with preamplification from image converter principles. Fundamental factors influencing the investigation were: ability to obtain necessary gain of additional brightness by amplification of the pickup tube signal with a conventional video amplifier, secure long integration times with background suppression and better contrast, simplicity of multiple viewing and signal measurements. Performance of the tube, related equations, diagrams and photos are included. Quantitative relationships are drawn between contrast, brightness, and image definition for one-stage intensified orthicon and wide-spaced image orthicon. Simulated astronomical objects observed by methods described in this report show the significance of the intensifier orthicon.

ARL TN 60-109 R.K.H. Gebel, A Super-Fast Recorder for Day and Night Observation of Space Vehicles Using a Light Amplifier Capable of Suppressing the Background and Discriminating Moving Objects. 17 p., November 1960. ASTIA AD 250256.

The usefulness of the closed circuit television light amplifier system capable of suppressing the background and discriminating moving objects is emphasized for detecting, tracking, and photographing missiles, etc., in flight. Special pick-up tubes have been developed which produce video signals from moving objects only, and the mechanism involved is explained for two different solutions. The importance of these solutions consists in that it is the pick-up tube itself rather than any auxiliary electronic computer, which delivers a signal representing the moving object only.

The improvements which may be expected by using an image converter tube as light intensifier between an optical system and the photographic camera are briefly discussed.

ARL TN 60-119 Z.N. Loh, Some Applications of the Poisson Distribution. 27 p., August 1960.

This report gives a brief summary of the formula and use of the Poisson Distribution. The introductory remarks are concerned with the meaning of the stochastic processes as a model of statistical processes and the special aspects of these devices.

The Poisson Distribution $P(n) = \frac{e^{-t} t^n}{n!}$ is known as an approximate exponential function which expresses the probability of random rare events. It also can be derived as the limiting case of the binomial distribution. In the tables, numerical values were calculated for small values of n and t, and graphs were drawn by connecting the points corresponding to the small values of t for specific values of n. The smooth curves show the approximations. The use of the Poisson Distribution function is illustrated in special examples, namely, light emission or absorption, and in connection with the theory of cosmic ray showers.

WADD TN 60-123 A.D. Cope and A. Borkan, Performance and Operation of the Image Isocon Camera Tube. April 1960.

The Image Isocon is a television camera tube which maintains a high signal modulation in the presence of excess scanning beam current. This results in a higher signal-to-noise ratio and accomodation of a greater dynamic range of light levels in a scene than can be achieved with tubes employing orthicon scan. The price paid for these improvements is a tube which requires more complex electron optics and procedures of adjustment than the image orthicon tube. Once adjusted the performance remains stable. Included in this report are typical operating potentials and the camera requirements for operation of experimental Isocon tubes being developed under this and a related contract.

WADD TR 60-145 H. Heil and W.J. Nolan, Thermal Imaging Transducer.

The atmospheric transmission of infrared radiation in the 8 to 15 micron region is such as to encourage its use for imaging for military purposes. This has not been practical in the past because efficient transducers capable of operating in the region have not been available. Since it is certain that it is hopeless to ever make the signal voltages of a superconductive bolometer which is of the order of 10^{-8} volts readable by the electron beam of an imaging tube, it was the aim of this contract to investigate the possibility of reading the relatively larger changes in the magnetic field associated with the super currents produced by the Meissner-Ochsenfeld effect. This report covers the research on this effect and its possible application to a thermal imaging transducer and describes in detail the theoretical and experimental research which is exclusively concerned at this time with methods of reading, sensing, or measuring magnetic fields, utilizing the change in a superconducting element produced by absorption of radiation.

WADD TR 60-147 F.H. Nicoll, A. Sussman, and H.B. Devore, Electroluminescence in Optical Amplifiers. 82 p., December 1959.

A two-color input, two-color output image intensifier panel has been constructed from solid-state materials. Its resolution is 40 lines/inch. A visible image (no infrared) at the input causes the blue output image to be excited. An infrared input image produces only a yellow output image. Various other approaches to two-color panel operation are discussed and some of the methods have been tried experimentally. Properties of photoconductive powders and electroluminescent materials have been investigated especially for possible use in these panels.

WADD TR 60-152 F.F. Hall, Jr., and R.K. Orthuber, An Analytical and Experimental Study Concerning an Infrared Image Converter System for Observation by Means of a High Detectivity Closed Circuit TV System. Report classified confidential. (Title and abstract unclassified.)

The sensitivity of edgegraph image converters used in conjunction with high detectivity closed circuit TV systems is derived and compared with observation using the unaided eye. Both transmission and low reflectance type edgegraph films are considered. It is shown that the use of electronic contrast enhancement substantially improves the minimum detectable temperature difference for such devices. Experimental data on the optical constants of selenium, lead chloride, and lead bromide in the region of their absorption edges are given. Low reflect-

ance films are described and the methods for production detailed. Various attempts to obtain intense, highly stable light sources and associated filters are reported. Tests made at WADD with a transmission edgegraph converter and an available "Cat Eye" TV chain are described. Recommendations for future work with such an image converter system are presented and continuation of the program recommended.

ARL TR 60-275 K.G. Guderley and M.D. Lum, On the Evaluation of Strongly Enlarged Photographs. 103 p., February 1961.

The accuracy of the evaluation of a photographic plate is limited by its grain structure. One approximates the value for the light density at a given point by the average light density in a small area (the "test area") surrounding the point. This paper establishes confidence limits for evaluation procedures of this kind. It is assumed that the grains on the photographic plate arise in independent random processes controlled by the local density of the light flux. In the evaluation procedure one counts the number of grains in the test area. Generalizing the method one attaches to each grain a weight factor depending upon the grain position within the test area and then determines the sum of the weight factors for the grains found in the test area. By such a procedure one can determine quantities related to the light density, e.g. the density gradient; one also can scan for patterns of a special kind, e.g. a sudden jump of the light density. For measurements of this kind probability theory predicts the expected value and the variance in terms of the light density and the chosen weight function. There are two kinds of errors due to the randomness inherent in the process of grain generation. The variance due to errors of both kinds must be minimized.

ARL TR 60-283 J. Lempert, Research and Reports on an Optical Amplifier. 76 p., May 1960.

The purpose of this contract has been twofold. During Phase A, the object was to find through research new solutions which lead to new and improved types of pickup transducers which are potentially suitable for future development in the military field, especially under low light level conditions. Definite improvement has been accomplished in the threshold by extra dynode multiplication and by image preamplification. Phase B called for investigating the feasibility of producing an imaging pickup tube which would be capable of operating under the vibration encountered in an aircraft in flight. The feasibility of constructing image orthicons with considerably reduced microphonics, and suitable for use in aircraft, was established.

ARL TR 60-284 G.A. Morton, J.E. Ruedy, A.J. Kelley, and S.A. Ward, Brightness Intensifier Study. 49 p., May 1960.
The basic limits of vision and image detection are discussed. Experimental results with the direct view intensifier are reported. A general discussion of pickup tube limitations concludes that the image intensifier orthicon is a very suitable pickup tube for a brightness intensifier amplifying a low light scene. Other intensification methods and storage operation of intensifier orthicons are also investigated and discussed. The use of the image intensifier orthicon for optical pulse ranging is suggested.

ARL TR 60-302 W. Rambauske and H. Kuesters, Automatic Optical Range Finder.
The different possible conventional methods usable for passive electronic range finding are analyzed. A new method is suggested, having considerable advantages in comparison to the conventional methods. A working model of this new method was designed and built for evaluation of experimental data and detailed descriptions are added to the report.

WADD TN 60-307 J. Lempert and G. Klotzbaugh, Research on Electron-Bombardment-Induced Conductivity Targets in Camera Tubes.
A method for calculating the resolution capabilities of a camera tube as a function of input illumination and tube design parameters is described. A description of experimental work on a successful method for obtaining a high-minification image in a combination magnetic and electrostatic focused image tube is given. Results of an investigation of different target materials of the electron-bombardment-induced-conductivity type are reviewed. The construction and test of experimental camera tubes, consisting of high-voltage variable minification image sections, high-gain targets of the electron-bombardment-induced-conductivity type, and scan sections with return beam multipliers are discussed.

ARL TR 60-315 R.K.H. Gebel and L. Devol, A Comparison of the Photographic Detectivities Attainable with and without Electronic Light Intensification. 21 p., October 1960.
A comparative mathematical analysis is made regarding the limits of performance of the closed circuit television type optical amplifying system, and of conventional methods, for obtaining and observing photographs of faint celestial bodies, having a magnitude comparable to that of the sky background. Primary attention is given to the cases in which detection is accomplished by visual observation of a photograph, but also the potentialities of electronic counting of the developed grains in a

photographic emulsion are considered. When using either conventional photography or photography aided by an image converter, the contrast between the celestial body and background, necessary for visual discrimination, is determined by the photographic emulsion or the limitations of the human eye, and an optimum exposure time exists.

With the closed circuit television system the instrumental and sky backgrounds can be suppressed electronically. Then the brightness of the image of the celestial body increases as the exposure time, but the brightness of the remaining background fluctuations, being statistical in nature, increases only as the square root of the time. Thus, as long as the device is capable of effective storage and integration of the electronic charge image, the contrast increases as the square root of the exposure time, and the ability to detect increases also.

ARL TR 60-324 A. Lallemand, The Electronic Camera. 16 p., November 1960.

It is possible to detect as little as one single photoelectron with the improved modern electronic camera which was basically conceived and first demonstrated by Professor A. Lallemand in 1936 and further developed since 1953 by him and his associates at the Laboratoire de Physique Astronomique of the Paris Observatory. This electronic camera is of utmost importance for astronomical work especially for obtaining spectroscopic recordings, because the exposure time necessary for conventional photography may be reduced with this device by a factor of more than 100. With it the spectra of distant nebulae have been recorded using an exposure time of two minutes and resulting in a better quality than can be obtained with the conventional methods in 10 hours 37 min of the same object by employing the same telescope. The electronic camera can be used with a grain counting device also for nuclear research work and a gain of 10,000 with respect to conventional photography is possible.

WADD TR 60-512 G.A. Morton and J.E. Ruedy, Research on Optical Amplification. June 1960.

The intensifier orthicon is a television camera tube developed for imaging at extremely low light levels. At these low light levels its sensitivity is one to two orders of magnitude greater than that of the standard commercial image orthicon. The report opens with two sections presenting the historical background of intensifiers. The fundamental requirements of image recognition and the electrical and physical properties of some of the basic tube components are given in the next two sections (III and IV). This is followed by two sections (V and VI) describing the intensifier orthicon and analyzing its operation in detail. The performance of the

experimental one- and two-stage intensifier orthicons and special tubes is presented in the next three sections (VII, VIII and IX). A discussion of some methods and means of improving this class of tube is then given (X and XI). Finally, various applications of the intensifier orthicon are described and illustrated (XII).

WADD TR 60-843 A.D. Cope, C.C. Peterson, and H. Borkan, The Image Isocon, a Wide Dynamic-Range Low-Noise Camera Tube. March 1961.

The Isocon camera tube derives its video signal from scanning beam electrons which are scattered by the storage target. Using sophisticated electron optics, the unmodulated fraction of the output current is reduced to a few percent of the highlight signal. The reduced noise introduced by Isocon scanning yields a greater dynamic range and operation at lower illumination levels than can be achieved with orthicon scan. A design of Image Isocon having minimum complexity is presented along with its measured performance. Analytical and experimental determination of the deflecting field modulation in the return beam is given which indicates that with optimum tube and deflection yoke parameters further improvements may be achieved.

ARL 12 R.K.H. Gebel, The Limitations in Resolution and Discrimination in Brightness Differences for Light Amplifier Systems Using Contrast Enhancement. January 1961.

The ultimate limitations in resolution and discrimination of brightness differences, determined by the quantum nature of light, at low light level observations with a light amplifier imaging system using contrast enhancement are treated herein. Simple equations are derived and the limiting situations are displayed by several graphs. The resolution achieved with an experimental tube is compared with the theoretically possible resolution. The low light level performance in contrast discrimination of the unaided human eye is inferior in comparison to the theoretical limitations of a light amplifier system that is possible by the present state-of-the-art.

ARL 122 R.K.H. Gebel, The Limitations for Night-Time Detection of Celestial Bodies Employing the Intensifier-Storage-Image Orthicon. (Reprint from The Ohio Journal of Science, May 1961.)

The purpose of this paper is to calculate the results one may expect by using the image orthicon and intensifier image orthicon for detection of celestial bodies during night time hours. The paper treats, in Part I, the image orthicon without intensifiers and calculates the limit in

detection determined by the scanning beam noise. In the Part II, the preamplification necessary for the intensifier section to overcome this scanning beam noise is calculated. The intensifier image orthicon is not necessarily the only arrangement for overcoming this beam noise. Intensifier image converter tubes effectively placed between the telescope and an image orthicon could produce the same results; however, such a solution is not suitable for use in flight vehicles because it results in a heavy bulky arrangement.

ARL 153 R.K.H. Gebel, Limitations in Detection of Celestial Bodies Employing Electronically Scanned Photoconductive Image Detectors. August 1961.

Theoretical limitations in the detection of celestial bodies by means of photoconductive sensors are investigated. Applicable simplified basic equations are derived for the maximum apparent magnitude number of a celestial body that is detectable with the commercially available vidicon tube, (a) assuming the most optimistic conditions and (b) as determined by background radiation during the day and the night, load resistor noise and other practical limitations. The equations are extended to cover the possible gain in sensitivity obtainable by using preamplification with additional image converter type tubes, and by integration over several scanning fields. The schematics of an easily constructed very sensitive experimental vidicon system used for the investigation are appended.

ARL 154 J.A. Hall and H. Shabanowitz, Research on Optical Amplification Employing Electronic Scanning Techniques. To be published.

The primary objective of the investigation summarized in this report was to determine, through research, a basis for subsequent development of a highly sensitive optical to electrical transducer or television camera tube for obtaining useful images at extremely low levels of illumination. An analysis of television camera tube limitations concludes that an advanced scanned optical amplifier of the image orthicon type, embodying suitable means of image intensification, is an effective approach to an ideal imaging tube performance limited only by statistical fluctuations of the input signal. Various means of intensifying the picture signal electronically, before the scanning process, are described.

Image amplification approaches investigated include the use of front surface secondary electron emission from solid members, in order to retain the feature of low voltage operation. The feasibility of applying the principle of transmission secondary electron emission by the

use of thin film dynode structures on prescanning-beam electron multipliers has been successfully demonstrated. Also investigated was the feasibility of reducing the energy distribution in the electron scanning beam to minimize noise sources in the tube. In addition, a means was invented and shown to be feasible for minimizing spurious signals in pickup tubes when viewing scenes with extremely high contrast. The research has, therefore, accomplished its objective of supplying the basis for the development of a new type of scanned optical amplifier, having a sensitivity and resolution potentially better than that obtainable from presently known television camera tubes.

ARL R.K.H. Gebel, R.R. Hayslett, and L.R. Wylie, An Introduction to the Problem of Photographing Artificial Satellites. To be published.

Some basic information useful for obtaining photographic recordings of celestial bodies, especially artificial satellites, is presented in this paper for the benefit of those who are not very familiar with astronomy. In the present space age this information may be quite helpful to those who are not trained in astronomy, but who are working in related fields. The historical origin of the magnitude system is discussed and basic equations are developed that will permit calculation of an approximate value of the exposure time necessary for different situations. This will, for example, give those who employ electronic detection methods a means of determining the order of photographic exposure time so that the speed made possible by electronic methods may be compared with the conventional photographic speed.

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1. OAR Fact Sheet (Office of Information, OAR, September 1961), p. 14.

2. Interview with Dr. Rolf M. Ammann, Chief, Plasma Physics Research Branch, ARL, by Mr. Garè P. LeCompte, Historical Division, OAR, 22 September 1961.

3. ARDC Form 98, 11 April 1955.

4. Interviews with Mr. R. K. H. Gebel, Solid State Physics Research Branch, ARL, by Mr. LeCompte, 23 August, 22 September, and 24 October 1961.

5. Ibid.

6. R. K. H. Gebel, A Portable Low Level Lightmeter (WADC TN-54-5).

7. Interview with Dr. John E. Clemens and Mr. Ben B. Johnstone, United Shoe Machinery Co., Xenia, Ohio, by Mr. LeCompte, 22 September 1961; interview with Mr. Gebel, by Mr. LeCompte, 23 August 1961; ltr., Maj. Gen. (ret) Albert Boyd to Mr. LeCompte, subj.: [Cat Eye], 10 October 1961; R.K.H. Gebel, Light Amplification and Its Importance in Modern Warfare (WADC TN-57-318), p. 3; John E. Clemens, Daily Diary Record, 18 December 1953.

8. Memo, Dr. Lee Devol, Chief, Solid State Physics Research Branch, ARL, to Col. Eugene C. Mallary, Chief, ARL, subj.: "The 'Cat Eye' Research Program," 22 December 1958; interview with Mr. Gebel, by Mr. LeCompte, 22 September 1961.

Chapter II

1. History of the Aeronautical Research Laboratory...1 July-31 December 1953, p.22.

2. R&D Project Card (DD Form 613), Project 7072, Research on the Quantum Nature of Light, 1 March 1957, 18 July 1958, 2 November 1959; interview with Mr. R. K. H. Gebel, Solid State Physics Branch, ARL, by Dr. David Bushnell, 1 February 1962.

3. R&D Project Card, Project 7072, 18 July 1958, p. 8.

4. Management Report (ARDC Form 111), Project 6219, Airborne Special Sensors, 29 April 1957; interview with Mr. Gebel, by Dr. Bushnell, 1 March 1962.

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6. Ibid.; R.K.H. Gebel, A Military Color Television System (WADC TN-58-114).

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6. R. K. H. Gebel, *A Portable Low Level Lightmeter* (WADC TN-54-5).
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5. Interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962.
6. *Ibid.*; R.K.H. Gebel, *A Military Color Television System* (WADC TN-58-114).

7. R. K. H. Gebel, A Super-Fast Recorder for Day and Night Observations of Space Vehicles Using a Light Amplifier Capable of Suppressing the Background and Discriminating Moving Objects (ARL TN 60-109, November 1960); interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962.

8. Memo, Mr. W. W. Baker, Programs Section, Plans and Operations Office, Directorate of Laboratories, WADC, to Lt. Col. E. A. Hawkens, subj.: "Meeting on Directorate of Laboratories Funding for Directorate of Research Work on Optical Amplifiers," 18 January 1954; memo, Mr. Baker to Photographic Reconnaissance Laboratory, WADC, subj: "Funding for Directorate of Research Task on Optical Amplifier," 4 February 1954.

9. Minutes of the Redlight Program Conference, 16-17 February 1954; ltr., Mr. H. Richard Blackwell, Executive Secretary, Armed Forces-NRC Vision Committee, to Dr. John E. Clemens, Chief, Physics Research Branch, ARL, 25 March 1954; R. K. H. Gebel, trip report, 7 April 1954.

10. Information in this paragraph is derived, passim, from the Correspondence File, Task 70827, 1 January 1953 to 1 January 1957, in the possession of R. K. H. Gebel.

11. Interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962; unpublished report in office files of Mr. Gebel.

12. Cf. Dr. Lee Devol, Engineering Physics Research Branch, ARL, "Proposed Item for WADC Weekly Technical Information Report," 9 May 1956.

13. Correspondence File cited in note 10, above; interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962.

14. Memo, Mr. Ben B. Johnstone, Asst. Chief, Physics Research Branch, ARL, to Capt. Auth, subj.: "Request for RCA 3/4 Ton Air Conditioner," 11 July 1955.

15. Interview with Dr. Lee Devol, Chief, Solid State Physics Research Branch, ARL, by Mr. Garè P. LeCompte, 24 August 1961; interview with Mr. R. K. H. Gebel, by Mr. LeCompte, same date; interview with Dr. John E. Clemens, United Shoe Machinery Corp., Xenia, Ohio, by Mr. LeCompte, 22 September 1961.

16. Memo, by Dr. Lee Devol [?], no date, describing the May 1956 demonstrations at Hq. ARDC; interviews with Dr. Devol and Mr. Gebel, by Mr. LeCompte, 24 August and 21 September 1961.

17. Ltr., Lt. William L. Smith, Asst. Adjutant, Hq. Air Rescue Service, to Cmdr., MATS, subj.: "Search Aids," 13 July 1956, and 3rd indorsement to same, Dr. Lee Devol to Cmdr., MATS, 13 August 1956.

18. Unsigned and undated memo, subj.: "Record of Telephone Conversation [Berry-Devol]," 4 February 1957.

19. Unsigned and undated memo, subj.: "Record of Telephone Conversation [Devol and Callan to Berry]," 4 February 1957.

20. Ltr., Mr. L. E. Michael, Operations Office, ARL, to CG, Army Electronic Proving Ground, subj.: "Support for Light Amplification Program," 6 February 1957.

21. Ltr., CWO Benjamin F. Harris, Asst. Adjutant, Army Electronic Proving Ground, to Cmdr., WADC, subj.: "Support for Program on Light Amplification," 7 March 1957.

22. Management Report, Project 6219, 29 April 1957; R&D Project Card, Project 7072, 1 March 1957.

23. Memo, Dr. Devol to Col. Eugene C. Mallary, Chief, ARL, subj.: "The 'Cat Eye' Research Program," 22 December 1958.

24. R&D Project Card, Project 7072, 1 March 1957, p.3.

25. Ibid., p.6.

26. R&D Project Card, Project 7072, 18 July 1958, p.4.

27. Interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962.

28. The text starting with this paragraph and continuing to the end of the chapter was largely written by Mr. Gebel himself on the basis of his personal experience and observations. However, a short published account of the work at Wittenberg can be found in R. K. H. Gebel and Lloyd R. Wylie, "The Cateye," Sky and Telescope, December 1958, pp. 84-85. See also the appropriate technical notes and reports among those listed in Appendix B.

Chapter III

1. Interview with Dr. Lee Devol, Chief, Solid State Physics Research Branch, ARL, by Mr. Garè P. LeCompte, 20 September 1961; ltr., Dr. Fred L. Whipple, Director, Smithsonian Astrophysical Observatory, to Dr. Devol, subj.: [Observation of Mars], 21 November 1956.

2. Ltr., Dr. Devol to Dr. Whipple, subj.: [Proposed Collaboration with AFCRC], 3 December 1956.

3. Interview with Mr. Edwin J. Callan, Executive Secretary, ARL Research Council, by Mr. LeCompte, 22 September 1961; interviews with Dr. Devol and Mr. Callan, by Mr. LeCompte, 24 October 1961.

4. Interview with Mr. R. K. H. Gebel, Solid State Physics Research Branch, ARL, by Mr. LeCompte, 21 September 1961.

5. Ltr., Dr. J. Allen Hynek, Associate Director, Smithsonian Astrophysical Observatory, to Lt. Gen. Donald L. Putt, DCS/D, Hq. USAF, subj.: [Testing and Evaluation of Light Amplifier], 26 March 1957.

6. Ltr., Gen. Putt to Dr. Hynek, subj. same as above, 11 April 1957.

7. Ltr., Gen. Putt to Cmdr., ARDC, subj.: "Electro-Optical Methods of Detecting and Tracking Scientific Satellites," 16 April 1957.

8. 1st ind. to preceding ltr., Maj. Gen. M. C. Demler, Dep. Cmdr./R&D, ARDC, to DCS/D, 29 April 1957.

9. Ltr., Gen. Demler to Dr. Hynek, subj.: [Testing and Evaluation of Light Amplifier], 29 April 1957.

10. Edwin J. Callan, Operations Office, ARL, memorandum for record, subj: [Cat Eye Negotiations], 4 April 1957.

11. Callan, memorandum for record, subj.: "Task 70827 - Light Amplification," 23 April 1957; Service Test Requirement (ARDC Form 171), Light Amplifier Assembly, 9 May 1957.

12. Callan, memorandum for record, 23 April 1957.

13. Callan, memorandum for record, subj.: "Record of Long Distance Telephone Call," 24 April 1957.

14. Callan, memorandum for record, subj.: [Cat Eye Negotiations], 25 April 1957.

15. Lt. Col. Robert G. Ellis, Asst. Chief, ARL, memorandum for record, subj.: "Long Distance Telephone Call," 25 April 1957.

16. Lt. Col. Ellis, memorandum for record, subj.: "Record of Conference Call between Lt. Col. Ellis and Dr. Devol, and Dr. Whipple and Dr. Hynek of the Smithsonian Astronomical Laboratories at MIT [sic]," 26 April 1957.

17. Lt. Col. Ellis, memorandum for record, subj.: "Long Distance Telephone Call," 26 April 1957.

18. Ltr., Col. Leslie B. Williams, Director of Research, Hq. ARDC, to Cmdr., WADC, subj.: "Electronic-Optical Methods of Detecting and Tracking Scientific Satellite," 1 May 1957.

19. Ltr., Luther T. Lee, Asst. Chief, Budget Division, Hq. ARDC, to Asst. for Development Programming, Hq. USAF, subj.: "FY 58 Service Test Requirements," 13 May 1957; Service Test Requirement, Light Amplifier Assembly, 9 May 1957.

20. Interviews with Mr. Gebel and Mr. Callan, ARL, and CMSgt. E. T. Tyson, Reconnaissance Laboratory, ASD, by Mr. LeCompte, 21 September 1961.

21. Capt. Marvin B. Sullivan, Directorate of Research, Hq. ARDC, memorandum for record, subj.: "Funds for Light Amplifier Assembly," 23 May 1957.

22. TWX, Col. Williams to Cmdr., WADC, subj.: [Cat Eye Funding], 26 July 1957.

23. Lt. Col. Ellis, memorandum of telephone calls, 25 July 1957; interview with Dr. Devol, by Mr. LeCompte, 21 September 1961; interview with Mr. Callan, by Mr. LeCompte, 22 September 1961.

24. TWX, Cmdr., WADC, to Cmdr., ARDC, subj.: [Cat Eye Funding], 12 August 1957.

25. Ltr., Maj. Gen. J. W. Sessums, Jr., Vice Cmdr., ARDC, to Maj. Gen. T. L. Bryan, Jr., Cmdr., WADC, subj.: [ARL-Smithsonian Cooperative Program], 23 August 1957.

26. Ltr., Col. Harvey P. Huglin, Cmdr., WADC, to Gen. Sessums, subj. same as above, 30 August 1957.

27. Memo routing slips attached to original copy of Col. Huglin's letter of 30 August 1957 (in Historical Division, OAR).

28. Ltr., Col. Huglin to Gen. Sessums, subj.: [Cat Eye Funding], 12 September 1957; interviews with Mr. Gebel and Sgt. Tyson, by Mr. LeCompte, 21 September 1961; interview with Mr. Callan, by Mr. LeCompte, 22 September 1961; Dr. Devol, "Smithsonian Cat Eye Program - Air Force Contributions," 4 August 1959.

29. Disposition Form, comment 2, Dr. Devol to Mr. Callan, subj.: "Cateye Memo," 30 September 1957; interview with Sgt. Tyson, by Mr. LeCompte, 21 September 1961.

30. George G. Barton and Richard S. Aikens, Electronic Image Conversion Program (progress report, Cambridge, Mass., 30 June 1959). pp. 1-2; interview with Sgt. Tyson, by Mr. LeCompte, 21 September 1961; interview with Mr. Gebel, by Dr. David Bushnell, 1 February 1962.

31. Barton and Aikens, Electronic Image Conversion Program, pp. 2-3; ltr., Dr. Devol to Dr. Hynek, subj.: [Cat Eye Test Program], 16 January 1959; ltr., Dr. Devol to Mr. Raymond K. Woo, Smithsonian Astrophysical Observatory, same subj., 3 April 1959.

32. Barton and Aiken, Electronic Image Conversion Program, p. 4.

33. Interview with Mr. Gebel, by Dr. Bushnell, 1 February 1962.

34. Information supplied by Sgt. Tyson and Mr. Gebel, March 1962.

Chapter IV

1. ARL, unsigned memo, subj.: "[Cat Eye] Results as of November 1957," 14 November 1957.

2. ARL, unsigned memo, subj.: "Synopsis of Program on High Sensitivity in Light Amplification," 14 November 1957.

3. R&D Project Card (DD Form 613), Project 7072, Research on the Quantum Nature of Light, 18 July 1958, p. 10; interview with Mr. R. K. H. Gebel, Solid State Physics Research Branch, ARL, by Dr. David Bushnell, 2 February 1962.

4. W. E. Woehl, A Multi-Lens Telecamera System With Image Orthicon Photosensors (Facet Eye Camera) (Air Force Missile Development Center, September 1961).

5. R&D Project Card, Project 7072, 2 November 1959, p. 3.

6. Disposition Form, Mr. Melvin R. St. John, Electron Tube Branch, Electronic Components Laboratory, WADC, to Mr. Gebel, subj.: "Cam-

era Tube Coordination Meeting," 24 November 1958; interview with Mr. Gebel, by Dr. Bushnell, 6 March 1962.

7. ARL, Physical Sciences Building Dedication Program (April 1958?); ARL, History of the Aeronautical Research Laboratory, 1 January-30 June 1958, p. 4; note written by Mr. Gebel, subj.: [Cat Eye Participation in ARL Building Ceremony], January 1962.

8. Ltr., W. L. Wilcock to Dr. Lee Devol, Chief, Engineering [later Solid State] Physics Research Branch, ARL, subj.: [Participation in Symposium], 21 July 1958; interview with Mr. Gebel, by Dr. Bushnell, 6 March 1962.

9. Army Engineer Research and Development Laboratories, Image Intensifier Symposium, October 6-7, 1958 (Fort Belvoir, Va., 1958).

10. Ltr., William E. Shawcross, Editorial Assistant, Sky and Telescope, to Mr. Gebel, subj.: [Request for Article], 25 August 1958; ltr., R. H. Maltby, Office of Information Services, WADC, to Mr. Shawcross, same subj., 29 August 1958; R. K. H. Gebel and Lloyd R. Wylie, "The Cateye," Sky and Telescope, December 1958, pp. 84-85.

11. R. S. Kardas, An Evaluation of Television Image Intensifier Techniques on a Long Focal Length Tracking Telescope (December 1959), p. 7 (for phrases quoted) and passim.

12. Memo, Dr. Devol to Col. Eugene C. Mallary, Chief, ARL, subj.: "The Cat Eye Research Program," 22 December 1958; interview with Mr. Gebel and Dr. Devol, by Dr. Bushnell, 2 February 1962.

13. Interview with Mr. Gebel and Dr. Devol by Dr. Bushnell, 2 February 1962.

14. Ibid.; interview with Lt. Col. William G. Ashley, Chief, Analysis Division, DCS/Plans and Programs, Hq. OAR, by Mr. Garè P. LeCompte, 1 September 1961.

15. ARL, unsigned memo (by Devol?), subj.: "Transfer of Optical Amplification Responsibilities to Technical Development -- Some Recent Events," no date (about 1 July 1959?).

16. Memo, Dr. Devol to Lt. Col. William G. Ashley, ARL, subj.: "Facts Regarding Transfer of Task 70827," 13 August 1959; interview with Dr. Devol, by Dr. Bushnell, 2 February 1962.

17. Note supplied by Mr. Gebel, subj.: [Stockholm Presentation], March 1962.

18. Interview with Dr. Devol, by Mr. LeCompte, 20 September 1961; interview with Dr. Devol, by Dr. Bushnell, 2 February 1962.

19. Interview with Mr. Gebel, by Dr. Bushnell, 2 February 1962.

20. R&D Project Card, Project 7072, 2 November 1959.

21. Management Report (ARDC Form 111), Project 4156, Thermionic and Solid State Electronic Technology, 4 September 1959.

22. Interview with Mr. Gebel, by Mr. LeCompte, 20 September 1961.

23. R&D Project Card, Project 7072, 1 November 1960.

24. Recommendation for Incentive Award (AF Form 1001), signed by Dr. Lee Devol and Col. Eugene C. Mallary, 22 October 1959, and attachments; additional data supplied by Mr. Gebel, January 1962.

GLOSSARY

AD	ASTIA Document
AF	Air Force
AFCRC	Air Force Cambridge Research Center
AFMDC	Air Force Missile Development Center
AFSC	Air Force Systems Command
ARDC	Air Research and Development Command
ARL	Aeronautical Research Laboratory
ASD	Aeronautical Systems Division
ASTIA	Armed Services Technical Information Agency
CG	Commanding General
Cmdr.	Commander
DCS	Deputy Chief of Staff
DCS/D	Deputy Chief of Staff/Development
DD	Defense Department
Dep.	Deputy
Dir.	Director, Directorate
ETL	Electronic Technology Laboratory
FY	Fiscal Year
Hq.	Headquarters
Ltr.	Letter
MATS	Military Air Transport Service
M.I.T.	Massachusetts Institute of Technology
NRC	National Research Council
OAR	Office of Aerospace Research
R&D	Research and Development
RCA	Radio Corporation of America
SLAS	Sequential light-amplifier system
SAO	Smithsonian Astrophysical Observatory
Subj.	Subject
TN	Technical Note

TR	Technical Report
TWX	Teletypewriter exchange message
USAF	United States Air Force
WADC	Wright Air Development Center
WADD	Wright Air Development Division

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